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CRYSTALS

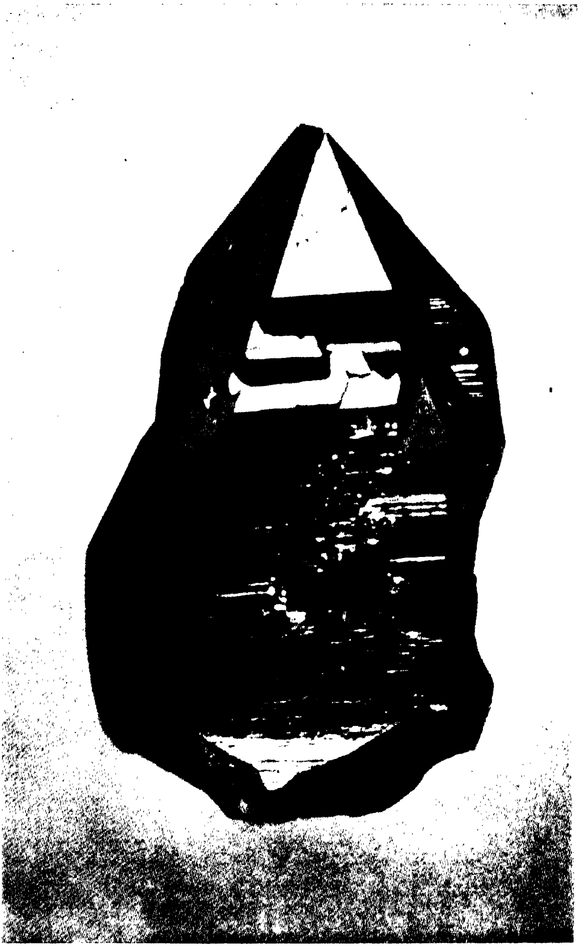

Plate I. Quartz crystal. (Morion).

CRYSTALS

Secrets of the Inorganic

by

J. KILLIAN

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FRAU ERIKA SPANN-RHEINSCH

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PREFACE

MOST of these ideas originated during the last eleven years, from the time when various spheres—each a single crystal—were being prepared at the Werner Works at Siemensstadt. However, it was not these fascinating mirror-like crystals, of whose existence I had at the time no idea, but an excellent book of P. P. Ewald—"Kristalle und Röntgenstrahlen"—which first drew my attention to such matters. It became progressively clearer to me that stones are not mere atomic constructions, as science tends to regard them. At the same time they do not correspond to our ordinary everyday conception of them as being deaf stone and dead matter with which we pave our streets and build our houses. Nor are they merely material for sparkling gems to serve our vanity as ornaments and our ignorance as toys.

The strange lack of feeling for the essence of the "inorganic", and particularly the loss of the immediate connection with nature which man certainly at one time possessed, must be attributed to the admittedly remarkable development of exact science. For the sake of the knowledge embodied in numbers, which science has given us, we have paid a high price: real understanding of nature and perception of its essential being, together with apprehension of its true character which is so closely linked with our own. Mathematical knowledge can perceive only the exterior aspect of nature: it is unable to probe within, into its true character. Yet it is apparently called upon to give an exhaustive picture of nature, and the idea has gradually established itself that with existing or possible scientific research nature could in the end be completely understood. This is a fundamental and fatal misapprehension which unless fought against will drive us finally into bare materialism, or—since the inner striving for understanding will remain unsatisfied—into frivolous and shallow mysticism. Exact science, as long as it is conscious of its limits, admittedly does us great service. Should it claim to present a complete solution it would become a serious menace to human thought and fate.

The seeker of absolute truth can not be satisfied with the shell of phenomena, but must search for the core, and for the real essence of things. We are no longer guided in our way by the ideas and methods of exact research, but rather by the help of a deep intuitive feeling. Such feeling lies not in the outer world but in ourselves. Inner vision must be added to and correlated with outer vision. The understanding which this gains for us is more than scientific, it is philosophic perception. In this sphere, where man is no longer confined by his subjective attitude, these two fundamental and distinct lines of thought and research meet; scientific and spiritual knowledge have become an identity. From an external point of view matter and spirit are diametrical opposites, but in this inner understanding they converge to their common point of origin. The nearer we come to his point, the more creative our knowledge, and the more universal and real our understanding.

This is the point of view which underlies research into the nature of crystals and inorganic matter. Throughout, I have taken actual knowledge of this branch of science as a starting point, and I have not to my knowledge evaded one single proved fact. Only in my interpretation have I reserved to myself that freedom which the conception of living nature requires. I hope that the closeness of nature to us, the intimate contact with the inorganic world which this method of investigation gives us, and particularly the abundant manifestations of the crystal principle, will justify this attempt and will have been amply worth while. Thus regarded, the crystal is in Meister Ekkehard's words no longer a "tupstein" which only proves "daz er ein stein ist", but is an "edelstein, der grôze kraft hât in dem daz er hât ein înstân, ein însitzen in sich selber", i.e., in its own being. The crystalline sphere, described by K. W. Hausser and P. Scholz in their essay, which was allowed to slumber like a sleeping beauty for a whole decade, surely had enough magic to make the mineralogist thoughtful and eager to probe the secrets of crystals.

Let this book then be given to the public. To make its contents accessible to all, the arguments are made as easily understandable as possible, and no special knowledge is assumed. The reader without technical knowledge will find crystallographic and mineralogical conceptions and facts explained in their respective places. In addition, the reader has at his disposal ample illustration provided by sixty-seven diagrams and seven plates.

It remains for me to thank all those who have given assistance in the work. I am especially indebted to Herrn cand. phil. Leopold Hiesinger, who was responsible for sixty-two of the drawings, and has given further useful service in the way of suggestions and extra work. Herr Lehrer Peter Fetty has had the extremely difficult task of conveying the appearance of the crystalline spheres by characteristic photographs. The seven plates show that his unsparing efforts have been successful.

Korneuburg, 16th May, 1937. J. KILLIAN.

"Steine hânt ouch grôze kraft von der glîcheit, die die sternen unde des himels kraft dar inne würket."—MEISTER EKKEHARD.

PART ONE

THE STRUCTURE OF INORGANIC MATTER

INTRODUCTION

THE THREE MODES OF EXISTENCE

THREE realms of nature can be distinguished, covering between them the whole of existence; the *inorganic*, the *organic*, and the *spiritual.* All non-living matter falls into the sphere of the inorganic—minerals and their degradation products, liquids and gases, in so far as they do not form part of a living organism, and of course the bodies of the universe (the whole variety of stars, meteors, cosmic nebulæ, etc.) All living matter belongs to the organic world. Included in this are not only plants but the bodies of animals and men. The spiritual realm is the world of consciousness which as far as we know only men and animals enjoy.

These three realms may be called *degrees* of existence. They differ completely from one another, but things may change their degree in the course of their history. Death lowers every organism from the organic to the inorganic degree, and conversely solid, liquid, or gaseous inorganic matter is raised to the organic degree when it serves as nourishment for a living organism. Finally, inorganic and organic matter can enter the spiritual sphere as objects of consciousness, but spiritual things can also be manifested in matter by the operation of such factors as art and craftsmanship, all kinds of manual dexterity, and the raising of plants and animals.

For our understanding, the *modes* of being are more important than the degrees. Inorganic matter "is" in a different mode from the organic, and the latter in a different mode from the spiritual, which in turn differs from the inorganic.

If an attempt were made to set out in complete form the modes of existence, it would be necessary in effect to lay bare the structure of all existence. Within the limits of an introduction, we must confine ourselves to emphasizing important differences in the manner set out below.

A. *The Inorganic Mode.*

The inorganic manifests itself most clearly in a mineral, though the purest expression is exhibited only in a crystal. It is from the latter therefore that we must derive our conception of the inorganic mode.

A crystal, whatever be its symmetry-class, or the mineral composing it, is a three-dimensional body bounded on all sides by crystal faces. It may happen that a crystal does not appear to be so bounded on all sides by faces, e.g. if it were grown on a matrix, or if hampered in growth by other individuals, so that it shows only a few faces (as in a polycrystalline mass). In these cases it is imperfect in certain places, i.e., it is a fragment. Nevertheless, its typical character is the closed form with continuous faces.

As we have seen then, a crystal is enclosed by plane faces. The edges are necessarily straight, being formed by intersections of these planes. The crystal shape is thus formed by planes, edges, and corners, the simplest elements of three-dimensional bodies in general.*

The crystal is a purely spatial body, and its essential character is independent of time. Although it grows much as a plant does, its shape depends only on its faces and angles, and not in any way on its size. As long as the former do not vary, its growth and its passage through time leave its fundamental character unaltered.

The crystal, as long as it retains its shape, or at least its structure, is always fully identical with itself; that is to say, it is complete at every instant. It is never in process of becoming, but always has being. Thus the crystal is independent of time and is entirely within the limits of space. But even within space it is incapable of motion relative to its surroundings.

The nature of the crystal is therefore essentially linked with inability to move and with independence in itself. Its existence is spatial, and its shape strictly mathematical, that is to say, determined merely by planes and straight lines.

A perfect crystal is therefore none other than the definition of the inorganic mode.

B. *The Organic Mode.*

The essence of the organic, its possession of life, exists not directly within space, but within *time.* If a pure and continuous example of this type were required, life itself would have to be analysed. For the organism is a projection of the organic into the world of bodies, and can illustrate this type only in a discontinuous manner. In fact, the organic, as a pure mode, is not available to our consciousness at all. We should have to be plants to live within it. Then, however, we would be able to recognize and describe it only to the same small extent as the plant. We ourselves remain entirely unconscious of the purely vital processes within our own organism (if healthy), despite the fact that it is the vehicle of the spiritual. We can thus approach the organic world only from the outside, and are forced into an attempt to note and interpret reflexes of the pure mode with the help of the living organism. Naturally the organic type appears purer in the case of plant than in animal life, for the latter approaches more nearly to the spiritual. The plant organism is thus the purest representation of the organic mode within space.

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*Curved faces, however regular, must be regarded as imperfect representations of the pure inorganic type.

All highly-developed plants consist of stem and leaf.* These are the two basic forms of the plant organism, and cannot be further derived. Goethe probably erred in thinking that the original plant form was the leaf, from which everything else was to be derived by metamorphosis. The plant would not be a plant if its essential character were embodied in the leaf. It should be rather the stem. For the most characteristic property of a plant is its lack of a boundary: the leaf, however, is clearly limited both in size and shape and must be regarded merely as an off-shoot of the stem.

The original type of plant form is represented by the haulm, *i.e.*, the stem, which is continuous with the root below and the vegetation apex above. An important aspect of its form is its length. Science assigns *no limit to growth in length of the plant*, but a limit exists to growth in thickness. Above and below, the stem appears to be unbounded, but the vegetation and root apices point to infinity. The particular significance of the vegetation apex is its unlimited growth. In the apex further cell-divisions, that is to say, lengthening of the stem, take place. The plant in contrast to the crystal is never completed. It is part of its character that its shape is not limited on all sides, but that along its length it is open at both ends.

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*Following Goethe, we are not taking into account here the lower forms (Cryptogams). The conception of being is clearly best illustrated by the highest development.

As the original plant shape we thus have a straight line unlimited in either direction. That the stem is not *a mathematical straight line, but has a certain thickness, is not part of the true nature of the organic*, but is due to its bodily manifestation in space. The organic is in general to be regarded not from the spatial but from the time-dimensional point of view.

The stem divides above and below (into vegetative crown and roots). This is not a relapse from, but a multiplication of the line-like shape. Instead of one we have any number of lines. Its being radiates towards infinity in all its apices.

The crystal, as soon as it exists, is always completed, the plant never. In all points a crystal recalls its former shape, whereas at every growing point the plant indicates a coming change in shape. The crystal is not concerned with time, whilst the plant develops its whole being within it. After cessation of growth, a plant is dead; a truly resting plant is inconceivable. It is the essence of the organic that it is alive.

The crystal, as a spatial structure, is three-dimensional, the plant, regarded as organic being which is subordinate to time, is one-dimensional. But even this one dimension (the stem) is nothing but a reflection of time in the spatial appearance (organism).

Growth for the crystal is immaterial; for the plant it is essential. The plant tends unceasingly to extend its own body beyond its original limits, for this is its very life. As a whole, it is in itself as incapable of motion as the crystal. But as a continuum, it extends constantly from a point, the fixed root-stock. As a unit it is extending itself with unchanged typical shape into infinity.

The continual extension from one point is the only motion which the plant can execute by itself.* In this bodily manifestation is reflected the innermost principle of the organic, the continuous flow of time.

As soon as the organic makes an appearance in space, *i.e.* in the inorganic world, it must somehow take on aspects of the inorganic type. That the plant world exhibits more or less striking examples of crystalline proportions is not to be marvelled at—it is included in the structure of being. Square stems, the symmetrical positions of twigs, leaves and flowers, the form of leaves (although they diverge from their originally regular form)—shortly, every mathematical aspect of the plant organism—are scarcely to be differentiated from an appearance of the inorganic (crystalline) type. Since, however, in the plant world the number 5 occurs as well as the numbers 2, 3, 4 and 6, whilst in the crystal a regular pentagon can never appear, it is only a proof that the shape of the plant falls into a higher category, namely the type of the organic, and is not limited to the confines of the inorganic type. Mathematics rules the crystal entirely, the plant only partly—that is to say, so far as the organic mode permits. This is why no one leaf of a tree is fully identical with another—not only in size, but also in shape—and why lines originally straight can be curved and twisted. For the final aim of the plant is life, not shape; its actual appearance is always the result of a struggle between its ideal configuration (the type) and the conditions imposed by its spatial environment.

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*Movements resulting from reaction to such stimuli as light, touch, etc., may be excluded in this connection. It is clear that insectivorous plants cannot be taken as representatives of the pure type. The same holds for primitive plants capable of free motion.

c. *The Spiritual Mode.*

The spiritual mode appears directly only within its own sphere, *consciousness*, and it is here alone that its mode can exist in a pure state. We must look within ourselves to appreciate this mode clearly. For the spiritual alone is capable of judging itself. Even the most fundamental expressions of the mind, such as language, music, religion, and philosophy, make use of a foreign medium, and exhibit this mode not clearly, but rather somewhat obscured. Indeed, only in *ideas* is the real spiritual mode revealed. To comprehend this mode, nothing short of a science of ideas would be required. For our present purpose we are concerned only with pointing out a few characteristics of the mental world. We are interested solely in inorganic structure, and will content ourselves with viewing the spiritual world as revealed by the medium of the organism. Naturally we now have to deal with the dual interference of the organic and inorganic (*i.e.* spatial) worlds, and not with a single interference which we found in *the case of plants. In spite of this double disturbance* the pure mode can still be clearly recognized. In any case, this method has the advantage that we are able to compare all three modes on the same plane (appearance in space). That we should take the human rather than the animal organism into consideration needs no further justification. For the former manifests the clearest and strictest projection of the spiritual into the world of bodily appearance.

Just as the plant takes up crystalline matter, so the human organism incorporates plants. In so far as man is subjected to this new type (the ideal) the organic must subordinate itself, just as did crystalline matter within the plant organism. It is undoubtedly present, though it cannot be recognized at first sight. What doctors call the "trunk" is indeed none other than the trunk or steam of the plant—a real trunk with a well-developed foliage (the head) and a useless and therefore degenerate root (the lower end of the spine). The configuration of other vertebrates, particularly of climbing monkeys, show us that legs are by no means to be regarded as divided extensions of the trunk, which would entail placing them in the category of roots. It is clear that legs and arms are morphologically homologous, but in man they have become distinct owing to a division of function entailed by his upright carriage. But even in our own organism the limbs are easily recognizable as two opposed pairs of branches on an upright trunk. (Hands and feet correspond to leaves, fingers and toes to the protruding ribs of leaves).

Man, unlike plants, does not grow indefinitely but has a somewhat sharply limited growth. The head being closed and the growth being limited is a transformation to the spiritual mode. From the strong curvature of the skull it can still be noticed with what might the tendency towards infinity has fought against the bounds of the finite. Just as in plants delicate juices flow towards the swelling bud, and just as the flowers glow with the most delicate and radiant colours, all man's sense organs have accumulated in the head, where his body is bounded. This is in order that the limits of the body may at least be opened by feeling, because sight and hearing can be brought into contact with the infinite universe, with the result that the beauty of vegetation is given a connection with the spiritual world.

The plant is wholly non-plastic, for its body can be resolved into one- and two-dimensional shapes, that is to say into stem-lines and leaves; the third dimension never comes into operation.* Plasticity is a contribution from the third, the spiritual category. In place of unlimited apical growth man has a limited though general surface growth. The trend towards infinity which in the plant is unhindered above and below, is here operative at every point in the closed trunk. It is no wonder then that the figure curves plastically.

The axis of growth of the organic world (the plant) remains the main axis even under the influence of the spiritual principle. Most vertebrates carry this axis in a horizontal position like an unsolved problem on their

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*Fruit, as the potential shape of the living plant, does not come into consideration here. Incidentally, fleshiness and curvature do not imply plasticity (*e.g.* cacti!).

backs, but man has replaced this axis in a vertical position. He has conquered the infinite and has thereby regained the freedom expressed in his upright carriage. The finite to him is an image of infinity.

Since the human organism, as well as the plant body, belongs to the world of space, crystal characters cannot wholly be lacking from man himself. His figure has been compared to a monoclinic crystal. This comparison while not absolutely correct, is very remarkable, because in contradiction to the organic and spiritual nature of man there is the fact that his body consists of two equal halves like mirror-images. The left side is a mere repetition of the right. The plane of symmetry (the "sagittal plane" of the doctors) is so clearly marked that it can scarcely be overlooked. On the surface, it is shown on the back by a groove along the spine, the "linea alba", and on the front by visible seams along certain soft parts. In the interior of the body various organs occur unpaired (heart, liver, stomach, etc.), but in the skeleton particularly, the frame-work of the body, the symmetry is not effaced. For even the skull, which in adult man appears as a rule to be without sutures, originates as two bone elements and hence in the embryo at least is subjected to the plane of symmetry. This symmetry plane is a purely mathematical element, and cannot otherwise be regarded than as a representation of the crystalline state in man. The human organism has thus incorporated in itself not only the organic mode (the plant) but also the inorganic (the crystal). Naturally, in this case as well as in the plant the crystal laws hold to a limited degree only: the organism overrides them and infuses them with life. For no part of a head is perfectly built and no half of a body ever corresponds mathematically with the other. It is in this overcoming of strict symmetry that the power of the individual is revealed. Too regular a head appears empty, just as a deformed one seems whimsical and insane. Symmetry, the crystal within us, should not be a binding law but a means to freedom.

As in crystals of higher symmetry, three mutually perpendicular axes can be imagined to pass through the human body; in a cubic crystal, the most perfect example of the inorganic world, the three axes are equivalent, but they have a different relation to one another in man. For they are nothing else than the spatial co-ordinates of the three modes of being, which co-exist in the body in remarkable harmony. The horizontal axis (left—right) perpendicular to the sagittal plane may be regarded almost as our crystal axis. This axis is as equivalent on the two sides as are all the axes of higher crystalline forms, for it joins the two enantiomorphous halves of our body and expresses the balance and unity which display the crystal within us. The vertical axis, as already mentioned, represents the axis of the organic mode within us; it is, as in plant-like organisms, polar, *i.e.*, it joins unequal parts—in fact the opposites of above and below. The third axis, the most important of all, stands perpendicular to each of the other axes, and therefore lies horizontally through the chest from behind. (The intersection of the three axes may be imagined in the middle of the chest, near the heart.) This last axis is the actual expression of the spiritual power—and it points in the direction of motion!

Our bodily form is clearly and harmoniously closed.

It is superior to the crystal, whose severity it converts into plasticity, and to the plant, whose thirst for infinity it has conquered. The surface is continuous at all points, not according to mathematical law, but with the greatest of freedom. It is for precisely this reason that the human body is separate from its surroundings in its own unique way. Thus it seems only logical and predetermined that it should be capable of movement within itself; the limbs can move and alter their position relative to one another—a power lacking both in plant and crystal.

However, more important than the inner movement is the ability of the body to wander, to move as a whole. The direction of intended motion is indicated to us by the third axis of the human frame.

This axis of motion is polar, like the limited axis of growth; in one case the distinction is between above and below, in the other between before and behind. If this axis of motion were as equivalent at both ends as is the right-left axis, a decision for definite motion could scarcely be imaginable. We are impelled forward by the blind and defenceless back. The whole body is in truth orientated to the front. Eyes, mouth, nose, forehead, and chest, as well as all parts which try to establish connection with the outer world, together with our most intimate parts—all these are directed forwards. No important part is on our backs. What was "above" for the plant is "ahead" for us. The plant grows upwards against gravitation, we hasten forwards into the arms of infinity. Thus the third axis, the axis of motion, is the deepest expression of our essential nature—the power of the spirit.

CHAPTER ONE

GENERAL STRUCTURE OF BODIES

Space and Matter

THE understanding of crystals to which we shall gradually be introduced in this part of the book is an understanding of the essential nature of the whole inorganic world, and we shall not be concerned at all with the structure of organic bodies. Even whole realms of the inorganic world, *i.e.*, liquids and gases and structures of moving systems (the cosmic universe and atoms) can be ignored here, because understanding of the crystal does not necessitate their study. The following observations are thus chiefly concerned with the structure of *solid* inorganic bodies of the earth's crust.

A. *Concept and Origin of Matter*

Experience shows us that every type of body has some colour, hardness, elasticity, sometimes a smell and taste, and always a certain weight. However, these properties are not necessarily associated with the idea of a body; they are thus not fundamental to the concept. Two characteristics are, however, associated with even the most abstract notion of bodies: size and shape. In the words of Kant: "Starting with the conception of a body, if I am to leave out all that which reason suggests, *e.g.*, substance, force, divisibility, etc., and which sensation perceives, there remain by this empirical method of approach still two things, size and shape."* A body, like a cloud, can lack all regularity and clear definition of form. The term "shape", however, usually conveys the idea of a well-defined form in space, so that we can more generally substitute the word "limitation" for "shape". Every body is therefore necessarily extended and at the same time bounded. A body which is not limited or is without definite boundaries we may call *matter*. Water, iron and salt, are matter, whereas ice-floes, bars of iron, and salt-crystals are bodies.

Dimension and shape are possessed even by geometric bodies, *e.g.*, a cube of side *a* or a sphere of radius *r*. But they have none of the other above-mentioned properties, and do not occupy a definite part of real space. They are not genuine bodies but schemata, empty shapes. Real bodies on the other hand are always forms filled with matter. Matter, not dimension or shape, bears such properties (as for instance, yellow, soft, heavy).

In the case of a real body we must then distinguish two aspects; the material and the spatial. The definition of a real body is: space filled with matter—or more strictly, spatially extended and limited matter.

Both space and matter are necessarily attached to bodies, but they are not equally fundamental, and can not be divorced from one another like partners in marriage. When a body disappears its space disappears also, but not its matter. Matter can form new bodies and thus create new space. For space appears together with a body from matter. Empty space on the other hand can not create bodies and can not concentrate to form matter. Matter is therefore the creator of both space and bodies.

---

*"Wenn ich von der Vorstellung eines Körpers das, was der Verstand davon denkt, als Substanz, Kraft, Teilbarkeit, etc., im gleichen, was davon zur Empfindung gehört, als Undurchdringlichkeit, Härte, Farbe, etc., absondere, so bleibt mir aus dieser empirischen Anschauung noch etwas übrig, nämlich Ausdehnung und Gestalt."

Crystals of diamond, garnet, the Karlsbad twin of felspar, and rock-crystal have all forcibly made elbow-room for themselves in the same manner. Only in shape have they followed their own particular laws. We find for instance the forty-eight faces of the diamond, the rhombic dodecahedron of garnet, the characteristic monoclinic forms of the felspar twin, and the peculiar pillars of rock-crystal. None of them in manifesting their special character became confused with large hollow spaces or air-holes. They remained true to their own process of creation and repelled all influence of foreign space. And even if they were formed in empty rock crevices they did not accept the shapes already present, in which they had to grow, but rather suppressed them. For as X-ray examination of crystals shows, each has its own spatial structure which the fortuitous shape of the crevice can not provide. Only a crystal can give to space a structure regulated by definite laws. The conditions already present could not serve as a basis for the structure. A crystal as it grows gives space a particular shape in the form of a mathematically determined structure.

Fundamentally, every body must be regarded as matter which, following its own will and law (although not always a mathematical one) has created space. A body can be created only by its matter assuming spatial shape. Generally speaking, *every real body is spatialized matter.*

B. *The Isolation in Space**

Bodies, as we have seen, have dimension and shape. Dimension we tend to regard as its positive, space-producing side, shape as its negative, terminating, and limiting side. With dimension we readily connect the conception of their inner impulse, their desire for expansion. But this view applies only to living things, not to dead bodies, and certainly not to space itself. In the course of formation, a crystal shows no trace of impulse, other than to arrange the particles exactly in their ordered position. This order is clearly pre-arranged, even where it has not yet materialized. It is not produced by the impulse, but exists from the very beginning, and it is only for the sake of this order or lattice that obstructions are shouldered aside. This lattice consists of a system of points that remain completely at rest and show no other tendency than to keep their place. Expansion occurs quite naturally by addition of new layers from the outside, and not by swelling from within. Space does not expand, but is formed.

In this way, a body appears as a firmly established structure, and with it the space within as well as the surface area. Area is not a continuous extension of a unity, but a process concerning a system of an infinite number of points.

If one wishes to explain the surface area of a body, as for instance a table-top, one meets the conception of points. To appreciate the length, one must estimate the length of the edge. This, however, can not be done otherwise than by looking at the two end-points and letting the eye glance up and down between them. If it is intended to be more accurate, another point must be utilized—the mid-point of the edge. Say that this is perhaps three-quarters of a yard as judged from the edge. For greater precision, the point to which half a yard might reach can be fixed with the eye. This latter distance could now be halved, and thus three equal parts would now result, each a quarter of a yard long. How could this distance be confirmed? Nine inches could be measured with the hand, or to assure precision, a ruler could be used. What else though is a ruler but a division of extension into points? To appreciate the length of an inch there is no other method than to insert point after point and clearly visualize every section. Again, the conception of space is made up of points. Shortly, to understand extension clearly, it must be resolved into points. These points must not be placed at random, but systematically, if a result is to be obtained.

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*Translator's note. In the German text the author uses the phrase "Schnitthaftigkeit des Raumes", which he states to be derived from Karl Faigl's book "Ganzheit und Zahl." The literal translation of the phrase is "The Intersectability of Space."

In practice one brings sub-division to an end at some stage or another. A carpenter when building a roof is permitted a few inches' inaccuracy; for him there is no such thing as a tenth of an inch, and even an inch may be left as an entity not worthy of further division. The skilled mechanic must carefully consider and divide every millimetre, and a worker with the microtome, who cuts preparations into thin sections, must not be satisfied with an accuracy of less than a *tenth of a millimetre. Finally,* X-rays *subdivide to a millionth of a millimetre* (millimicron) and allow us to calculate distances between crystal particles of the order of an Ångström unit (a tenth of a millimicron). Further division of the very minute is so far impossible. But does division stop here altogether? If an Ångström exists, then there must also be the half and tenth of it. In short, the process of sub-division can not stop as long as any stated unit remains undivided. Division must proceed without end, for only the point really elucidates space. Points arise, however, only by infinite sub-division. What is true for one dimension must rationally hold also for the other two; the entire body appears as a three-dimensional system of points.

Why now can an area not be appreciated sharply and definitely as such? It is because area is an uncertain conception. As soon as one tries to clarify it, it resolves itself into discreet though infinitely close-set points. The point is an evident thing, and with it space is created. Area and line are obscure: only the point gives meaning to space. The point has no extension and occupies no space itself, but it is precisely the point that is the fundamental basis of space. Only through its point can space manifest itself directly to us.

The structure of matter took no part in this argument, and we must conclude that according to our ideas space is constructed of points. Thus space, which alone we can conceive and know consciously, has a certain structure; it consists basically of many points arranged according to some law. In order to understand its true nature we must divide space first into areas, then lines, and finally into points. Only the latter tell us what it really is. Only when *fully resolved* is space clear to us—it manifests itself as "isolated units".

c. *The Structure of Bodies*

A body is an essentially spatial formation. If one tries to grasp matter as such without its spatial implications, the result is rather similar to that which occurs in the concept of areas. Just as in that case extension resolved itself necessarily into systems of points, so here, however far the division may be carried, we invariably encounter *structure*, and we never have a real conception of *matter*, for matter is expressed through structure and hidden within it.

Consider an ordinary piece of wood such as a carpenter might use. At first sight one imagines that the matter of the wood can be seen directly. This is not so, for (considering a planed plank) there are evident several lighter and darker layers lying next to one another, some of which seem denser and the other more loosely constructed. According to the type of wood, there may also be a more or less evident and perhaps glossy cross-striation, together with scaly growths, etc. But even the separate rings and layers are by no means homogeneous throughout; they clearly consist of fibres which on magnification under a lens or microscope prove once more to be capable of subdivision. The greater the enlargement, the finer will be the structural parts observed. What is sought is the *matter* of the wood (the cellulose), but this will never be found. There is nothing but structure, *i.e.*, spatial formation. Even the strongest magnification gives no completely homogeneous picture. It is well known that all living matter is composed of cells, but neither the nucleus nor the cell-wall are finalities or real uniformities, *for they are still formed of distinguishable parts. Because of the wave-length of light, there is a limit to microscopic resolution* (about 0.0002 mm.). Invariably, the part last seen shows structure and not uniformity.

The case is the same for inorganic substances (minerals and rocks). From the coarse structure of porphyry or of some granites to dense chalk or finely-divided basalt, there exist all intermediate stages, and corresponding ranges of structure may be followed on the microscopic plane. Finally, X-rays show us that even the perfectly-formed crystal consists of many discrete particles separated from one another by a few Ångströms, in fact by less than a millionth of a millimetre. Only amorphous minerals show no structure. But even they must have a definite texture (although this might be impossible to prove because of their slight differences in light refraction), for they are solid gels (colloidal precipitates).

In short, to whatever extent we may be able to divide up bodies with the aid of light, we always meet structure, and structure alone, *i.e*, smaller and smaller particles which appear themselves to be further divisible. Should a means ever be found of demonstrating particles a thousand times smaller than those shown to us by X-rays, would we then necessarily reach final units? Nothing suggests this; rather the opposite may be assumed. We have no indications whatsoever that such a limit to structure could exist.

GENERAL STRUCTURE OF BODIES

The idea necessarily suggests itself that body- and space-structure are connected. In fact it seems self-evident that bodies, as spatial representations of matter, are isolated in space, and must consist eventually of infinitely small particles (matter-like points). Naturally, bodies show many intermediate structures. Wood for instance shows annual rings, fibres, and cross-striation. For wood is not merely empty space, but also matter, and furthermore it is matter subjected to the agency of the organic world; and this agency must manifest itself in some way. But even inorganic minerals exhibit differentiation depending on the substance (the chemical compound) from which they are made. Every body is matter and space, with the result that the particular structure of matter must appear in the general structure of space. It is of fundamental importance that continued resolution into particles leads to change in structure but never to a final unit. In all substances, organic and inorganic, one must consider structure as continuing indefinitely.

CHAPTER TWO

MATHEMATICAL AND NON-MATHEMATICAL STRUCTURES

Crystal and Colloid

THE forces which build up bodies are deeply mysterious. There is no doubt that they originate in matter, but their effect is merely spatial, and they determine the inner structure ("fine structure") and outer appearance of all bodies.

According to their relation to mathematics all more or less clearly-defined structures which can be described fall into two fundamentally distinct categories. One of these includes those minerals whose particles are subject to a mathematical geometric law, the other comprises all other solid bodies. Strictly speaking only crystals are built according to mathematical laws, and we may therefore call the mathematical category of bodies the *crystal-category*.

The forces by which the atoms are held together in the crystal are very clearly orientated and their effect is not influenced by any other force. At points where two crystals of a grouping touch or even penetrate into one another, a mutual disturbance of their laws of structure results, and the arrangement follows no simple plan. On each side of the plane of contact the crystalline arrangement may be undisturbed, but on the plane itself, however, the mathematical law appears to be broken by the opposition of the two differing structures. Thus the contact may be totally irregular, broken, torn, or vaguely defined. The sum of these unorientated planes forms the *texture* of the crystalline group, crystalline mineral, or rock. The cohesion of the aggregate is therefore no longer insured by those forces which act within a single crystal, but by forces connecting individual to individual. Since physics refers to forces between bodies in contact as forces of adhesion, we may call this non-mathematical category the *adhesion category*.

The clearest structure, the one showing the most unequivocal conformance to a law in all the inorganic world, in fact, in the whole realm of spatial existence, is exhibited in the crystal. It is not only based on a mathematical plan (like a flower perhaps, or the human organism) but its structural law is fully obeyed with mathematical accuracy and strictness even as far as concerns its invisible particles, provided always that no outside influence has altered its formation. Although the leaves of a lilac show a symmetrical arrangement, yet a precise examination reveals that each leaf has two unequal halves. The same holds for animal and human bodies and in fact for all organic matter. Small distortions in the actual proportions indicate no fault, but are inherent in the nature of living organisms. In the crystal on the other hand the minutest deviation from its geometrically-defined shape and every slight interruption of its structure—even if the rupture or included foreign body can not be detected microscopically—mean imperfection, and must be regarded as faults, for the perfect crystal is characterized by perfect geometrical form. The most finely-sharpened blade of a microtome can not be compared with the polished accuracy of a perfect crystal. The crystal is mathematically determined not only without, in the external appearance defined by planes, edges, and points, but also within, in the arrangement of every atom. Every cleavage-face, every percussion figure, and every diffraction pattern produced by exposure to X-rays furnish clear proof of this. The crystal is a unique and incomparable element in the universe.

The range of the crystalline world is far larger than might appear at first sight. Not only fully-developed—perfect or imperfect—crystal forms fall into this category, but also every mineral substance with random, *i.e.*, non-mathematical, outline, which shows a mathematical order in its internal structure, apart from whether the crystalline nature can or can not be recognized by the eye. The crystal is characterized not so much by its outer shape or "habit" as by its fine structure or "crystal lattice".

Leaving crystals, we must find it strange and almost inexplicable that inorganic bodies exist whose constitution does not conform to some strict law. Nevertheless such bodies constitute a large part of the visible crust of the earth. How do these apparently unordered bodies retain their coherence? What is their spinal cord which saves them from continual disintegration and enables them to retain their solidity and particular characteristics? For investigation shows us that every body possesses its own particular hardness, its cleavage

—or fracture planes, and its definite properties in general. A pebble which we tread heedlessly underfoot is not protected by mathematical law; yet, how strikingly it has withstood the severe test of many thousands of years, and how stubbornly it retains its character which we can recognize at a glance, though we are not able to measure and calculate it. Every piece of sandstone retains its properties, and every crumb of soil has its own character. Thus even non-crystalline bodies are not entirely unordered aggregations of space, and matter, but possess their own specific and often very definite structure.

If the definition: "A body is spatialized matter" holds, then the most perfect, in fact the only perfect body, is the crystal. For according to this conception, a body is the more perfect the more completely it is reduced to existence in space. But space is all the more perfectly realized according to the degree in which a given line or area approaches to a straight line or plane. The simplicity of the bounding surface is the factor which leads to the surprising abundance of space inside a train, for instance, while a landscape of undulating hills makes space, though a thousand times larger, appear strangely unimpressive. Only the straight line reveals full volume, and every curve renders some part dormant. How severe and alert does space seem inside Gothic cathedrals (the interior would sometimes be unbearable in its simplicity were it not for the diffused and soft lighting)! And how mild and dream-like appears space within baroque churches, which as a result need the brightening effect of windows on vaulted arches! An obelisk rises up like a dagger, completely converted into space, whereas a sand-heap veils space rather than liberates it. The crystal, however, limited only by planes and edges, and regulated within by straight lines, is nothing but space within and without. Matter has become wholly spatialized. Here there is nothing dormant or indefinite, and everything has been realized. In a cubic crystal, where only the right-angle is concerned, space is displayed with absolute clarity. A right angle is the greatest possible extension between two infinite straight lines. All possibilities which exist in space are fully exhausted in the cubic crystal, and the focus of the spatial universe, *i.e.*, the basis of the realm of bodies, is the perfect crystal, and above all the cubic crystal.

Is it any wonder then that the hardest mineral, the diamond, crystallizes only in the cubic system? Such a crystal, subjected to the most clear and rigid laws, should be intrinsically indestructible, and should be capable of disintegration only through its own agency. Only diamond scratches diamond. Should one not expect every cubic crystal to be perfect? For what should be raised to perfection if not that which is governed by the strictest law? Still, crystals of all classes and systems occur with numerous deficiencies, and the metals in particular, which for the most part belong to the cubic system, form in general distinctly poor crystals. However, in one respect this peak of the inorganic world preserves its real superiority: crystals of all systems show a tendency, a kind of longing to assume the cubic shape, the most perfect form of non-living bodies. (Cf. p. 122.)

On the other hand it might be expected that bodies with non-crystalline shape, *i.e.*, bodies with internal crystalline structure only, which thus fall short of complete domination by law, could maintain themselves but with difficulty. But even this does not follow. Admittedly they are not usually as rigid and inflexible as a crystal, which under pressure remains as a rule unaltered or else breaks. Because of their relatively indeterminate build the former are more elastic and changeable in shape; however, what they lose in tendency for self-preservation they gain in tenacity, which means that in many ways they have a more persistent existence than has the uncompromising brittle crystal. Therein lies yet another proof that the adhesion-structure of matter is not in any way arbitrary, but corresponds to its properties and is based on chemical qualities and outside conditions.

Nevertheless the crystal remains the actual form of the inorganic world; the forces which build a crystal hold the universe of non-living bodies in strict subjection. In fact, if the crystal had not been an element of the creation, the earth and every star would fuse into a single point, and the universe of space would disappear into nothingness. In the crystal lies the key of the structure of the visible world, and the ideal shape of every non-living object is represented in the crystal. Up to a certain point all matter tends towards the crystalline state.

What is the earth's crust composed of, as far as is known to us? By far the greater proportion consists of broken or unfinished crystals. Some owe their existence to imperfection of growth, others to the fate of all earthly bodies, disintegration. All crystalline and dense minerals as well as rocks such as granite and gneiss consist of granulated, more rarely lamellated or fibrous formations, crystal fragments which mutually interfere with their respective growths into completed entities. The shining, glistening planes of a fragment which appear at the point of breakage are numerous minute crystal planes which were unable to develop completely. It is thus that mountains originate from the tendency to crystallization. Their inner structure is full of billions of small and yet smaller crystals—embryos which were arrested in development and now have no hope of achieving completion. Though they are unfinished, they yet remain crystals, for they carry a mathematical structure within them. A most binding law safeguards their essential nature, but not their existence. While still in existence a crystal remains unaltered in its essential structure—to change it would mean annihilation. But like everything else it is subject to outer influences. Even the crystal breaks up, is crushed, disintegrates, or is dissolved. Mountains sink slowly as rubble, sand, or dust, into the valleys, and are levelled as fertile soil from which delicate plants draw their nourishment. This is the fate and end of crystals.

Since, however, the crystal has no concern with time, growth and decay are foreign to its essential nature. Of importance is only the condition in which it actually exists. Initial imperfection or later disintegration are of equal indifference to the crystal, for each involves a departure from its nature. We can say with confidence that almost the whole of the earth's crust results from various processes of crystalline disintegration.* In fact even water and air are but molten or volatilized crystals. But the case of liquids and gases is distinctly different, and may be omitted from our discussion. Let us consider only the solid bodies of the earth's surface, as phenomena due to the disintegration of crystals.

Actually the only unbroken crystals are those formed in "suspension", *i.e.*, single crystals regularly formed on all sides, such as are sometimes found loose in sand (*e.g.*, diamond, garnet). Even the individual members of a crystalline group suffer a certain irregularity and can never be perfect where they touch, because two different planes meet and cohere where one crystal intrudes into the other. Unavoidable and more extensive are the imperfections of fully grown crystals. Since these individuals are not separated by an even surface from the matrix which gives rise to them, they remain necessarily incompleted at one end. The transition to the crystalline matrix lacks a uniform boundary. Since, however, the individuals normally stand closely packed and are often inclined to one another, a further irregularity can often be observed due to mutual contact and conflict between neighbouring crystals.

Polycrystalline groups and decayed ores constitute the first order of imperfection. The crystalline form, to whatever system it may belong, is no longer perfect, although to a greater or lesser extent its character may remain unobscured.

The second order of imperfection concerns a degradation of crystalline structure, whether it be in homogeneous rocks such as marble and rock-salt, or in composite rocks such as granite, crystalline slate, etc. These specimens still possess a fine structure, but apart from this exhibit only planes bound irregularly together, *i.e.*, without edges. Thus there is no defined form. Naturally, the degree of imperfection is not influenced by the size of the crystals, nor by any preference for growth in none, one, or two directions—*i.e.*, a preference for growing in the form of grains, needles, or plates. On the other hand these factors influence the appearance of a mineral—whether coarse, fine, or dense, the latter comprising minerals whose individuals can no longer be picked out by eye. There results from this a great variety of texture. Minerals and aggregates of coarse structure (marble and granite), of flaky, scaly texture (gneiss, slate), of pointed or needle-like structure (stibnite, hæmatite), and of fibrous criss-cross texture (nephrite), down to the glowing asbestos-like fibres of "cat's-eye", all show the same degree of irregularity, for all of them exhibit the beginnings of crystals, but not completed shapes.

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*Coal and other deposits derived from organic material play scarcely any role in the composition of the earth's crust. Deposits of chalk, shells, etc., are real, though once organic, products of crystalline disintegration.

From a well-formed crystal with sharp edges and polished faces down to the finest dust particle of a mineral there is no gap, but there exists a continuous range down to complete annihilation of the crystal itself. All intermediate steps, from the crystalline grouping to the last invisible dust particle follow to some extent the mathematical structure of inorganic matter. They represent the crystal character of which they are but a broken imperfection.

Even so the mineral world shows phenomena which must seem strange to us after our study of the crystal, for there are forms which lack all vestige of straightness of line and planeness of surface and which bend and twist freely and indefinably in space. Examples are the pipe-like forms of aragonite, and the bent wiry hair-like branched forms of some precious metals (gold, silver and copper). Even these consist for the most part of orientated individuals (perhaps distorted octahedra), but the crystal has lost its dominating influence, and the new forms have shaken off almost entirely the ties of mathematical law without at the same time finding any definite new guidance.

The softest and most irregular forms originate as a result of the complete extinction of all mathematical law and crystal character in the colloidal state, and outwardly these minerals (*e.g.*, opal) appear as knobby, grape-like and mathematically indefinable shapes.

The *colloid* is a type of spatialized matter which has lost to an extreme degree any trace of crystalline character. In chemistry one understands by colloid a finely dispersed substance whose particle size lies between 100 and $1\mu\mu$[*] in diameter. In this narrow zone the foundation of the inorganic world seems to be shaken and the red dawn of a new world rises before us.

In the colloidal state the states of aggregation have lost their significance almost completely. A jelly (glue or gelatine) of certain viscosity may equally well be described as solid or liquid, since it unites the properties of both states. Further, the colloidal dispersion of a substance exhibits very clearly a fundamental property of gases, *i.e.*, free motion of particles. The Brownian movement (Fig. 1) can be observed under the microscope in milk as well as in smoke. The minutest gas bubbles occluded in crystals are in constant quivering motion throughout thousands of years.

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[*] $1\mu\mu$ (1 millimicron) is the millionth part of a millimetre.

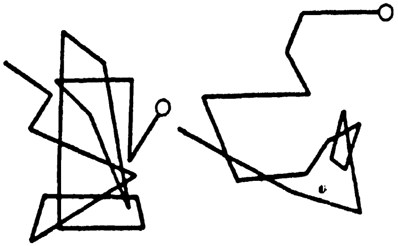

Fig. 1. Paths of two particles in Brownian movement. (From W. Ostwald, "Die Welt der vernachlässigten Dimensionen.")

The colloid can no longer be understood from the pure spatial point of view. Not only are the particles not ordered by a law, but the arrangement is subject to a continual flux. Quite apart from Brownian movement, the colloid is undergoing continual alteration. Although this may at times be a slow process the particle size, viscosity, light refraction, and colour effects, as well as all other properties, are incessantly changing. The colloid is therefore no definite final state of matter, but is in the course of time subjected to spatial, optical, and electrical variation. The colloid, unlike a crystal, does not exist, but is in a continual state of happening. But even at some definite moment a jelly, for instance, can hardly be defined spatially. It appears as thought matter is freed from the laws of bodies. The isolation in space seems in this case to have lost its existence. The gel is in no way dependent upon the crystal.

Colloidal division is the state of matter which appears to be associated with colour. In this state colours show their greatest power and beauty, and disappear outside the limits of the colloid. (*Vide* Chapter IX). That which is mathematical law for the crystal is colour for the colloid, the proof of its fine structure, and the image of its temporary internal state. It is a deep marvel that colour, the glowing language of flowers, should awaken in the colloid.

The question now arises; can the colloidal form still be counted unconditionally within the limits of the inorganic, whose very laws it bluntly denies? Actually the colloid itself is dead matter, which can be derived from inorganic and organic substances alike. But in view of the fact that it is subject to constant change, such as occurs in the realm of life, and in view of the fact that it does not associate itself clearly with space, it becomes very puzzling that it can dry up in the form of a gel and can become a solid body which appears like a stranger in the world of the inorganic. And what amazing strength these peculiar formations have! If a gelatine solution is dried on a plate of glass (for instance, in an oven at about 100°C.) the gel contracts. At the same time it adheres tightly to the glass plate so that large shell-like fragments are torn from the glass. Dried colloids play their part in mineralogy also: opal, agate, and others are of such origin.

How can this determined entry of colloids into the world of bodies be explained? Does it not appear as though there must be two centres, in such a way that from one of them crystals, from the other non-mathematical structures and amorphous bodies originate?

If we consider molecular solutions, *e.g.*, common salt in water at ordinary temperatures, or phenol in water at more than 70°C., two methods of adhesion for the smallest particles exist: mathematical and non-mathematical aggregation. The first leads to formation of crystals, the second to the colloid. The two states are divided entirely from one another and there is no bridge between them. The smallest of crystals is formed, and clearly bounded from the liquid (mother liquor), whilst the colloidal particles do not separate so clearly, that is to say, they represent merely progressive concentrations of the solution, and they are often penetrated by the solvent and surrounded as if by a hood which binds them. The crystal at all times can enlarge only according to planes and straight lines and can never assume a different structure. Colloidal particles, however, can enter into more or less loose or firm combination with one another, and can thereby form manifold, but non-crystalline structures (similar to honeycombs, nets, or cells). However far the coagulation may proceed and to whatever extent the particles may bind to form greater complexes, a crystal can never originate from them, for in the crystal every *atom*, even the very first, must be mathematically orientated; a colloidal mass can in no way become a crystal*, nor can it enter such a crystal. There is no transition and no combination between these two types of body, which quite definitely both exist as complete strangers, each according to its own laws, from the first compounding of particles up to the completed crystal or to the solid coagulated mass, *i.e.*, dried gel. The atoms (molecules) may in some circumstances even be the same ones, but their properties, and hence the bodies they form, must always be different from one another.

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*The transformation of colloid to crystalloid is not to be imagined as a transformation of one form into the other, but as a re-distribution in the sense of Spann, ("Kategorienlehre", p. 194). In other words, the colloidal structure must become a molecule, before crystal formation can occur.

Both types of formation, crystal and colloid, appear to be "generally possible states of matter", at least of mineralogical substances. An Austrian mineralogist, F. Cornu, declares that every crystallized mineral must have its colloidal double.

If we look not merely at amorphous minerals but at all matter of non-mathematical structure, it becomes clear that in great part they belong to the organic: tar, glue, rubber, all saps, shells of molluscs, bones, wood and all the bodies of plants, animals and men, *i.e.* of all living matter which we know. It is, in fact, most interesting that "it so happens that all phenomena of life appear in colloidal media only" (Ostwald). Further, organisms can incorporate matter in the colloidal state only. In the case of animals and men this is obvious as they nourish themselves on animals and plants. It is much more important, however, that plants, which must derive their matter from the realm of minerals *i.e.*, the inorganic, can take up this matter only in colloidal distribution from the soil or from a liquid. Thus, only in the colloidal form can inorganic matter be taken up by life, and it can be changed into living substance in this way alone. For only the colloid with its changeability is able to discharge itself—as does all living matter—into the stream of time.

Is there any need for a clearer proof that non-mathematical colloidal structure must be anchored in the organic? Life needs the colloid and attracts it towards itself. Must life not be the focus of the colloidal state which it makes and bears? The whole realm of non-mathematical structures can hardly be understood otherwise than by reference to the organic. All the world of crystals, from the largest crystal to crystalline dust, disintegrates for the sake of the organic in order to give nourishment to life and living bodies! The crystal had to disintegrate for life on earth to be possible at all. Must not life then be considered from the very beginning as part of the plan of creation? Crystals disintegrated because life demanded it. Rocks and mountains, however, appeared because the crystals built them up. Life and crystal are the two foci which can draw matter into their respective spheres and can utilize it in their own characteristic manner. The crystal desires crystals, and life colloidal substance. If life were not part of the essence of this world only crystallized minerals would exist, and no amorphous ones. Opal was probably colloid which might have entered life before it sank back into the mineral world and before it coagulated. The amorphous members of the mineral kingdom were originally formed for the organic world, but were left untouched and unused by life and resumed the inorganic state. In the sober language of science they are dried gels (colloidal precipitates). When coagulating they still have something of the crystal within them, of the crystal which they had lost completely at the magic approach of the organic.

As the crystal finds its image even in the bodies of plants, animals and men, in the shape of mathematical form, foreign to life, (symmetry axes and sagittal planes) it is itself illuminated in its highest members by the ray of distant life (*e.g.*, curved faces on the diamond crystal; determination of habit according to the changing surroundings, etc.). The winding shapes of iron ore accommodate themselves towards the organic world and the fibrous serpentine appears to reflect plant-like forms (such as flax or hemp).

The crystal is a strict, remote, formation completely unrelated and inaccessible to the living world. Breakage of its structure does not merely mean destruction of the crystal, but at the same time it means a yielding of its barriers and a successive approach to the organic. Substance must be released from the bond of mathematics and of inorganic laws in order to enter new forms, *i.e.*, those of the living. In this way the crystal melts through all steps of adhesion down to the colloid in which it falls prey to its own destruction and to the laws of the organic. Those who regard nature, not merely as a physico-chemical mechanism, will apreciate in this connection more than mere coincidence.

> "Got ist mir nêher denn ich mir selber bin, mîn wesen hanget dar an, daz mir got nâhe unde gegenwertic sî. Alsô ist er ouch eime steine und eime holze, aber sie enwizzens niht."
>
> MEISTER EKKEHARD.

PART TWO

THE CRYSTAL

Introduction

EVERY completely formed crystal shows faces, edges and corners. But points, lines and planes are the simplest elements of space. Every curvature is to be regarded as a departure from the straight line and at the same time a complication. Strictly speaking, the line is the purest, in a certain sense perhaps the only absolutely spatial component. That is why we can no more hope to define it than space itself.

The crystal is mathematics transformed into body, and is composed of geometry, inside and out, in the same way at every point. It is the strictest way of building up bodies, it is space become visible. Once we have found its pure concept we will have recognized space as the definite mode of being characteristic of the inorganic.

In actual fact the essence of a crystal is not exhausted by its mathematical relationships; it extends beyond the material and the spatial, where neither shape nor relative numbers exist. To grasp its innermost characteristics we must first understand the fundamental ideas concerning symmetry relationships in the world of crystals.

CHAPTER THREE

MATHEMATICS OF CRYSTALS*

GREAT credit is due to the German scientist M. von Laue (1912), who for the first time passed X-rays through crystals' and thereby discovered their fine structure. The appearance of certain diffraction patterns makes it possible to determine the relative packing of the smallest parts of crystals, the atoms, though in general this is possible only in higher classes of symmetry (particularly in the cubic and hexagonal systems). And it has been proved (as one might have assumed from the outer shape of crystals) that in their inner structures the atoms are arranged in order according to mathematical laws. In fact, even here in the smallest dimensions, as in the whole shape, only straight lines exist. All atoms lie along lines and crystals can be described only by straight lines or planes. The system of straight lines, which in its simplest form represents the arrangement of atoms according to space-lattices, is described as the crystal lattice. The final structure of the crystal is known as soon as this lattice is determined. Every X-ray structure analysis ends with the determination of the crystal-lattice.

Although at present we have no certain knowledge

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*May be omitted.

of the fine structure of crystals of lower symmetry (*triclinic, monoclinic and orthorhombic systems*), we are entitled to use the theory of lattices in general in order to gain rapidly and simply an idea of the symmetry relationships of crystal systems. We are not concerned with the structure of particular substances but with the general principle which underlies the lattices.

The lowest symmetry is shown by crystals of the triclinic system. They possess neither a symmetry plane (by which the crystal may be divided into two equal halves which are mirror images of one another), nor do they possess a symmetry axis (about which the crystal may be turned into coincidence by less than a full revolution), but possess only a centre of symmetry.* This relation is expressed by the fact that the planes appear in pairs, *i.e.*, that every plane has a parallel counter plane.

Parallelism of planes or of lattice lines is the fundamental conception of crystal structure. The most general scheme of a crystal-lattice is thus obtained in the following way:

We construct in a plane a group of parallel lines g_1 with the distance apart a_1, and we intersect this group at an arbitrary angle by a second group g_2 with the distance a_2. The system of parallelograms obtained is referred to as a lattice plane (Fig. 2). Now we continue into the third dimension by giving the lattice plane a parallel displacement along lines which are not perpendicular to the lattice plane but oblique. The distance

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*From our point of view we may disregard the class which does not even possess a centre of symmetry.

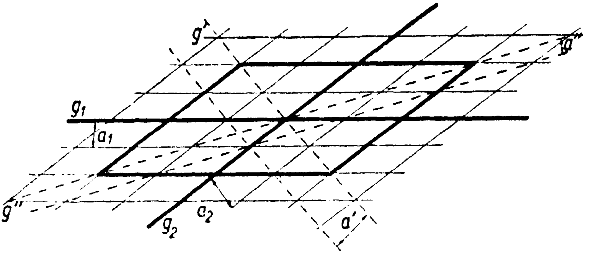

Fig. 2. Oblique net-plane.

apart of the single planes is a_3. If we now imagine the points of intersection of lines occupied by atoms (or ions) we obtain the scheme of a triclinic crystal (Fig. 3). The groups of lines of the plane have now become groups of planes in space. The atoms are exclusively arranged according to lines. If now the three groups of planes are made to intersect, we have as points of intersection the position of all atoms. But it must be pointed out that the atoms may be joined by other straight lines, as for instance in the original plane by groups g' and g'' (Fig. 2), which must necessarily have different distances (a' and a''). The greater the distance between the atoms along any chosen line the

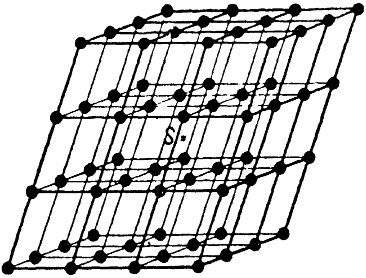

Fig. 3. Triclinic lattice.

closer are the lines of the group; the total number of atoms is fixed from the start and must be the same in all groups of lines. Just as we can draw arbitrary groups of lines in the plane, we can also draw arbitrary groups of planes in space. The lattice plane is determined by two groups of lines, the complete lattice is unambiguously determined by three groups of planes. All other lines and planes are no longer free but are dependent on the already fixed positions of the atoms. The possibility that the crystal can be defined by different lines and planes explains the fact that the crystal shape may show prism and pyramid faces. The appearance of a cleavage plane, which is not parallel to any of the existing crystal faces, can be understood only by this means: for not all planes which exist in the crystal (there are, in fact, an infinite number of them) will appear as actual bounding faces. The more densely a plane is covered with atoms, the greater necessarily is the distance between planes of the corresponding group, and the more probable therefore that there will be a cleavage in that direction.

Whether there are such simple triclinic primitive lattices we do not know; it is in fact improbable, for even among structures determined so far in the cubic system none has been found corresponding to the simple primitive lattice, but the symmetry relationships of the triclinic system do appear clearly in this scheme. The triclinic crystal does not possess a symmetry plane, *i.e.*, no section can be made through the crystal so as to divide it into two equal halves related as mirror images (as, for instance, the human shape by the cut through the sagittal plane). But it does not even possess a symmetry axis; for whatever axis it may be turned about, it will come into coincidence only after turning through a full revolution (360°). The symmetry is thus exhausted by the parallelism of faces which is equivalent to the presence of a centre of symmetry in which all lines meet which join the mid-points of pairs of faces (the point S in Fig. 3). Had we originally displaced the lattice plane of Fig. 2 parallel to itself along a line which was perpendicular to the plane of the paper, we would have arrived at the scheme of a monoclinic lattice. The plane which passes through the mid-point of the line of translation parallel to the two original planes is then the plane of symmetry. It divides the crystal into two equal halves related as an object to its mirror image. At the same time a diad axis, *i.e.*, a symmetry axis, appears which permits the crystal to be brought into an identical position after turning it through 180°. (Diad or "twofold" axis because two positions of the crystal are identical so that it can not be seen whether the crystal has been turned or not.) In our scheme it would be the line joining the mid-points of the two basal planes.

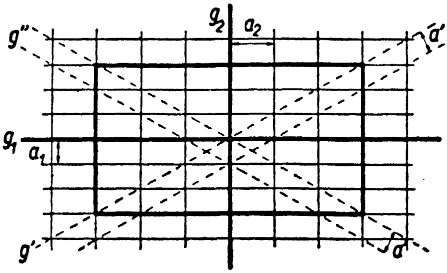

Fig. 4. Rectangular net-plane.

The symmetry may now be increased in two different ways. *One is to allow two groups of lines in the plane* to intersect at right angles so that they form rectangles (Fig. 4). On allowing this lattice plane to be displaced perpendicularly into space one arrives at the scheme of an *orthorhombic* crystal* (Fig. 5). The angles between the axes are right angles, but all lines or distances between planes are different (a_1, a_2, a_3) or as follows necessarily, the three axes of the unit cell are non-equivalent (length, breadth and height are of unequal size). Through the crystal three mutually perpendicular symmetry planes may be placed (differently shaded in Fig. 6). The three crystal axes have become at the same time diad axes.

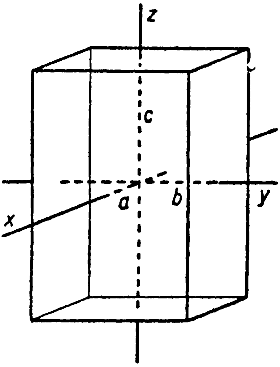

Fig. 5. Rectangular parallelopiped.

If we proceed in this way and equate a_1 to a_2 (Fig. 7), we obtain by perpendicular parallel displacement the form of a tetragonal crystal (Fig. 8). The basal planes are squares. The pinacoid faces are congruent rect-

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*The term "orthorhombic" is not applied to the crystal system because of its pinacoid faces, which are rectangular but because of the prism form, which is in the shape of an open pipe of rhombic section. (See Fig. 20).

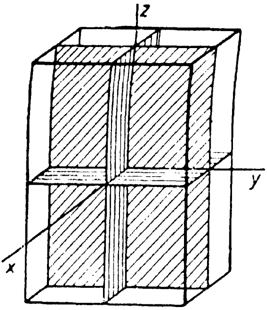

Fig. 6. Symmetry planes of the orthohombic system (holohedral class)

angles. The crystal possesses five planes of symmetry (Fig. 9); in addition to the three former planes we have two further planes through the diagonals of the square basal planes. The x and y axes are equivalent, each a diad axis; the z axis on the other hand, which is perpendicular to the square base, is a tetrad axis of symmetry, so-called because the crystal comes into an identical position four times when turned through 360° about that axis.

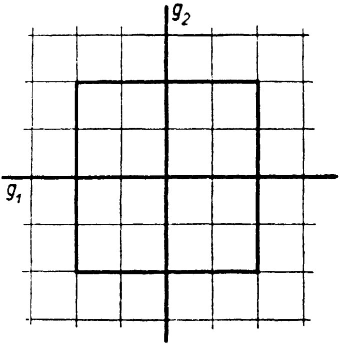

Fig. 7. Square net-plane.

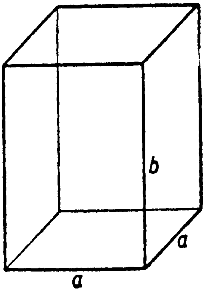

Fig. 8. Rectangular parallelopiped with square base.

If finally all three distances between lines become equal $a_1 = a_2 = a_3$) one arrives at a cube, the fundamental shape of the cubic system (Fig. 10). As far as symmetry planes are concerned we now have three mutually perpendicular main planes and two planes each along the square diagonals, *i.e.*, nine planes in all. All three crystal axes are equivalent and represent fourfold axes. Further, there are four body diagonals (the lines joining pairs of opposite corners) as threefold, and the six lines joining the mid-points of pairs of opposite edges as twofold axes, and we have reached thereby the highest symmetry which is possible in the world of crystals.

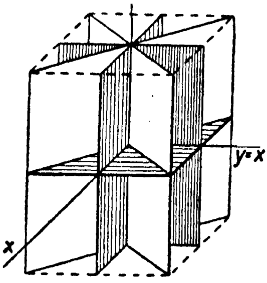

Fig. 9. Symmetry planes of the tetragonal system (holohedral class).

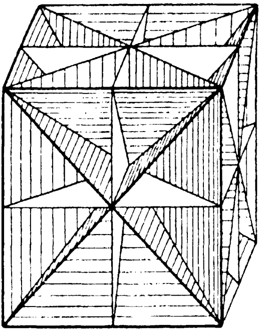

Fig. 10. Symmetry planes of the cube.
(From Tertsch, "Einführung in die Mineralogie".)

If we start with the monoclinic system, the symmetry can be increased in such a way that in the basal plane one chooses instead of the oblique angle at the intersections of the two groups of lines, not the right angle, but a third of the complete angle, *i.e.*, 120°. If the distances along the lines thereby remain different (a_1, a_2) we still have the symmetry of the monoclinic system, but a definite angle (120°, or 60°) is employed and not any arbitrary one. If, however, a_1 is equal to a_2 the symmetry is increased by one step, for a third group of lines appears entirely equivalent to the other two: $a_1 = a_2 = a_3$: at every intersection the lines include six angles at 60° (Fig. 11). As basal plane we have a regular hexagon, and the prism faces arising from it have the symmetry relationships of a hexagonal crystal (Fig. 12). It shows a horizontal main plane of symmetry, three vertical symmetry planes parallel to the three axes, and three further planes at right-angles to the axes. The vertical crystal axes (z) is a hexad, the three horizontal axes (x_1, x_2, x_3) are diad axes, as are

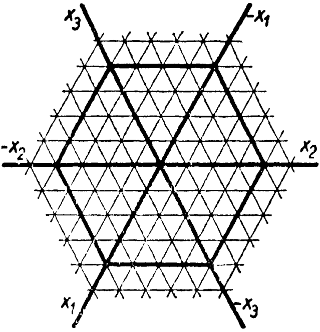

Fig. 11. Hexagonal net-plane.

the three other lines at the intersection of the horizontal and vertical planes of symmetry.

The trigonal system may be explained as a hemihedral form of the hexagonal system which is formed by the lack of certain symmetry elements.

We have discussed only the holosymmetric classes of every system, which contain all symmetry elements which are possible within the system. In every system, however, certain elements of symmetry may not appear,

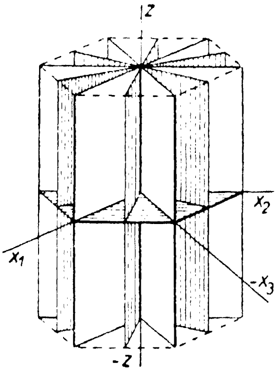

Fig. 12. Symmetry planes of the hexagonal system (holohedral class).

so that the symmetry is divided up manifoldly, and mathematically thirty-two symmetry classes can be described which in fact with the exception of two, have been observed in actual (naturally occurring or artificially grown) crystals. There can be hardly any doubt, since nature does not show any loop-holes, that even the two crystal classes which have not so far been found in nature also exist in the realm of crystals, so that the crystal world signifies nothing other than an immediate and complete representation of pure space. Admittedly this perfection concerns only the general symmetry relationships, not, however, possible exceptional cases within the single crystal systems or crystal classes. As to how far in that direction the theoretical possibilities of pure space are exhaustively utilized in the crystal systems we can as yet have no final opinion as long as not all structures are open to investigation by X-rays. It can, however, be said with certainty and independently of all future structure analyses, that crystals, regarded from the point of view of their lattice alone, are formed by absolute space without intermingling of any foreign influence, and without interruption by any other mode of being. In other words: the realm of crystals is a direct representation of space.

CHAPTER FOUR

CRYSTALS AND MATTER

NORMALLY one speaks of "crystalline matter" and means thereby the chemical compound forming the crystal. Silica for example forms trigonal, trapezohedral quartz crystals, calcium carbonate trigonal, scalenohedral calcite crystals, calcium sulphate orthorhombic anhydrite crystals and when hydrated monoclinic gypsum crystals. Strictly speaking the expression "crystalline matter" in its normal meaning is untenable. A chemical substance as such can not form a crystal: a compound in the chemical sense does not appear in the crystal, for a substance in a crystal is no longer a chemical compound.

A chemical substance, *e.g.*, gold, Au, or common salt, NaCl, has various properties: weight, colour, hardness, elasticity, specific heat, solubility, and fixed melting and boiling points. It also has certain chemical relations to other substances. All these properties have essentially nothing to do with the crystal itself. Sometimes this is self-evident. Gravity for example has no effect on the crystal, for it grows independently of its orientation in space, not like the plant, which always grows against gravitational force. A crystalline rod can grow horizontally, or vertically upwards or downwards, without its growth being influenced. The colour is not necessarily determined by the structure of the crystal. Normally it is produced by foreign matter finely distributed in the crystal. It can often be altered or even made to disappear by light or heat without the crystal itself being affected. If the crystal itself had such a property, it would be lack of colour. For the tendency towards lack of colour in crystals becomes obvious in comparison with non-crystalline substances. (Bergkristall compared with opal, Iceland Spar compared with dense limestone, etc.) A perfect crystal in fact must be colourless. (Cf. Chapter IX). By dissolving it in a solvent, or by fusion, a crystal can be destroyed but not altered in its character.* As long as it exists, its spatial relationships and lattice are preserved. The particles may (according to the ideas of physicists) oscillate freely about their equilibrium points, but the points can not be moved, and it is just precisely the arrangement of these points which forms the crystal! According to the colour, streak (colour of the powdered mineral) and lustre, hardness, specific weight, fusibility (in an open flame or with the help of a blowpipe), action of acids, etc., the mineralogist identifies individuals, and the crystallographer similarly does so by goniometric measurements of the angles between faces. Actually crystal shape and cleavage are important means of identification for the mineralogist, as there exists a very definite relationship between crystal structure and matter, which we are about to discuss.

The body of a crystal is composed of two factors: space and matter, or, as we are now able to say, crystal structure and substance. The division into two factors is carried out completely so that in the pure crystal no matter is possible, *i.e.*, the substance, as far as it still possesses any properties at all can not enter into the crystal, because the crystal is a pure structure in space; matter, however, is not. Even the most characteristic property of matter, that which appears to build up the crystal, the chemical affinity, is superseded in the crystal structure, *i.e.*, it is resolved into purely spatial relationships. For the crystal, as we now know definitely, is not built up of molecules (the smallest particles of a chemical substance) but of atoms (or ions) which do not as such determine the properties of the substance, but only when in molecular combination. And it is precisely the molecule, the bearer of properties, which does not appear in the crystal.

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*About inversion on change of temperature, see p. 121.

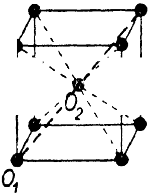

Fig. 13. Body-centred cubic lattice. (Unit cell).

This may be illustrated by a few examples. First, however, we must widen our conception of lattice structure in order to understand the following crystal structure, for as already mentioned, among the structures so far determined none have been found with the simple primitive lattice. Even the simplest known structure of the cubic holosymmetric class, the body-centred cubic lattice, is already a derived lattice. Its fundamental shape, the cell which forms its basis (as organic tissues are made of living cells), is a cube with *an atom at each corner and at the centre.* (Fig. 13). A number of elements crystallize with this lattice as a basis, for example lithium, Li, sodium, Na, iron, Fe, etc. The cube-cell is well beyond the limits of submicroscopic size: the length of the edge is in the case of lithium 3.5, in sodium 4.3, and in iron only 2.86 A.* Since in the crystal, cube is linked to cube in all directions of space, this structure is equivalent to two primitive lattices combined together, with a displacement from one another of half the body-diagonal of the cube. (Viz. Fig. 14, where it is evident that the centering atoms form cubes of the same size as do the outer atoms). One of these lattices can be obtained with O_1 as starting point (Fig. 13), the other can be derived in the same way from O_2 by mere translation (movement along the corresponding edges). If we imagine that one of these two lattices (*e.g.*, O_1) is occupied by atoms of cæsium, the other (O_2) by atoms of chlorine, we obtain the crystal lattice of cæsium chloride, CsCl. The two component lattices are completely equivalent,

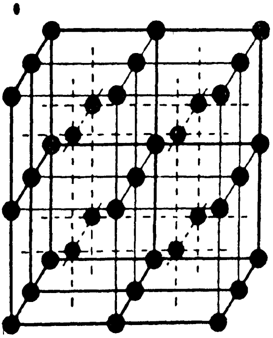

Fig. 14. Body-centred cubic lattice. (Eight unit cells.)

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*An A (Ångström) is the ten millionth part of a millimetre.

and thus the two elements can be inter-changed, *i.e.*, it is immaterial whether the O_1 or the O_2 lattice be regarded as the lattice of Cs. The two elements form each a lattice of their own; the two lattices are exactly equal in size and shape and interpenetrate in such a way that the displacement corresponds to half the body-diagonal. This is the state of affairs exhibited in the crystal. The CaCl molecule does not occur in it as such. The chemical affinity of the two elements has been resolved completely into spatial relationship.

There can be no doubt that the lattice itself is the result of the combined action of the two elements. This is proved without ambiguity by the fact that other Cs-compounds crystallize with the same type of lattice but with a different length of cube edge; in the case of cæsium bromide, CsBr, for instance it is 4.29, in the case of cæsium iodide, CsI, it is 4.58 A. The same cæsium atom thus forms three different compounds with cubic lattices of three different sizes, and it is not possible to determine what particular distance corresponds to the cæsium itself. It can not be stated otherwise than that in any particular compound the structure, the crystal lattice, is the determined factor, whilst the relative distances, the will as one might say of the separate elements to form a lattice, is the factor which needs to be determined and which receives its ultimate value only from the lattice into which the element has entered.* Thus not only has the substance as such disappeared in the crystal, but the spatial value of the atoms has to a certain degree become dependent on the lattice! It is equally true to say that the lattice stands in an exact relation to matter, as will be shown later, for it is clear that in the absolute crystal the lattice alone exists. The lattice, however, is a purely spatial relation. All properties of matter have been extinguished, *i.e.*, have been resolved into the relations of the lattice.

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*Attempts have been made to allot certain radii of action to the atoms and to explain the distance between two atoms in a lattice as the sum of two radii. Within a reasonable approximation this theory is valid in the case of the alkali halides, but it has been shown that it has no general applicability. This means then that atoms possess no constant radius.

The unconditioned and general applicability of the spatial becomes even more remarkable in the crystal lattice of a single element. Since sodium, for instance, already forms by itself a body-centred cubic lattice, its own atoms exist at different distances from one another,

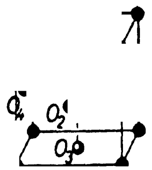

Fig. 15. Face-centred cubic lattice.

for the length of the edge of the cube is a, whereas half the cube diagonal is $a\sqrt{3}/2$. How may this be explained? Can the same sodium atoms have different relations amongst themselves? Are they separated into two types each of which forms its own lattice? The explanation is that the atom as such has no significance apart from spatiality, but even this does not appear as a fixed property of a single atom, but is allotted and prescribed by the lattice symmetry (distances a and $a\sqrt{3}/2$). There remain nothing but space relationships and discrete points which lack all property and are termed atoms.

The *face-centred* cubic lattice may serve as an example of another type of lattice. The fundamental cube of this type has atoms at the eight corners and also at the centres of the six faces (Fig. 15). The continuation of this lattice in all directions of space gives an arrangement of four inter-penetrating primitive lattices. The origins of the three centring lattices (O_2, O_3, O_4) are displaced with respect to the fundamental lattice (O_1) by half a face diagonal $a\sqrt{2}/2$. (The atoms of the three other face centres as can readily be seen no longer belong to the base but fall partly into the neighbouring cube. It must be remembered in particular that every corner atom belongs to eight cubes in exactly the same way, just as every cube has eight atoms at the eight corners). We are confronted here with the same facts as in our first example. For in the face-centred lattice also a series of elements crystallize; these are such metals as gold, silver, copper, platinum and others. Here also atoms of the same type stand at differing distances from one another (a or $a\sqrt{2}/2$) and have lost their characteristic nature and even their identity, as far as this was founded on that nature. As lattice points, *i.e.*, as mathematical elements, they are actually equivalent, and the different elements do not exhibit different behaviour in their respective crystals. The substances and its concrete properties can not enter the crystal as such but are locked up in the atom, so that the latter appears to have lost its properties on becoming part of the lattice.

Even a number of binary compounds, *i.e.*, those which are composed of two elements, crystallize according to the same type, which in this form is named after rock-salt. The *rock-salt* lattice (Fig. 16) is none

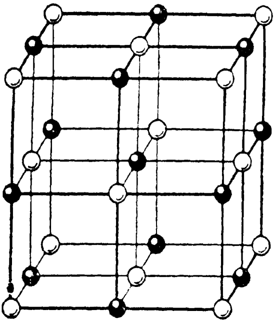

Fig. 16. Rock-salt structure.

other than an interpenetration of two face-centred cubic lattices each of which is formed by one element. (Our sketch illustrates the unit cube of the sodium lattice, which corresponds to two half cubes of the chlorine lattice). Again, the two lattices are absolutely equivalent, and the elements can thus be exchanged for one another. Colour, taste, solubility, etc., of salt can of course be observed, as in finest powdered salt, but always as properties of the substance and not of the crystal. For the rock-salt lattice is neither white nor soluble, nor does it taste of salt, but is completely lacking in substance and properties. And although salt is highly diathermic (*i.e.*, allows heat rays to pass without appreciable absorption) it is not the crystal which is responsible, for in that case periclase, MgO, which crystallizes in the same lattice, and oldhamite, CaS, which has almost the same size of unit cell, would possess the same properties almost in the same degree.

In the crystal lattice, whatever the symmetry class or space group, all matter is neutralized into a mere support of the mathematical structure, and becomes completely devoid of properties. As in mathematics, where no property exists but the mathematical, so in the lattice none exists but the spatial. The spatial aspect of the lattice is unmixed and uninterrupted, and there is thus no possibility of matter entering the crystal as substance. What we can grasp in the hand is admittedly matter, but the absolute crystal is neither visible nor tangible. Even purely spatial relations, which would contradict the nature of crystals and the supersession of matter, *i.e.*, which might prescribe a certain symmetry to the atoms as a fixed property, are hardly possible in the lattice.

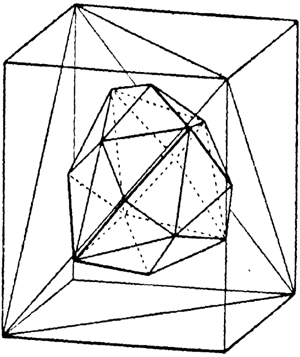

Fig. 17. Hexakistetrahedron.

Admittedly the symmetry of atoms in a crystal, particularly if one is concerned with one single element, can be determined from the lattice within limits (the highest or lowest symmetry) and one can at least imagine that the diamond lattice is composed of atoms of hexakistetrahedral shape (Fig. 17). But as soon as one seriously assumes that this symmetry is a property of the carbon atom, a position of considerable difficulty arises. The diamond lattice (Fig. 18) is composed of two face-centred cubic lattices which appear displaced from one another by a quarter of the body diagonal. The carbon atoms (at the corners of the cube) are so arranged that around each atom there are four neighbours at the four corners of a tetrahedron, with the original atom in the centre. The distance from one atom to another is 1.53 A. (This is the smallest interatomic distance which has so far been found in a crystal lattice—with the exception of atomic groupings or radicals, such as CO_3 in calcite, which may show even smaller internal distances: cp. Fig. 28.)

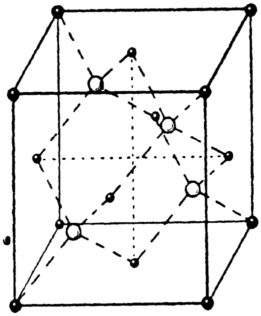

Fig. 18. Diamond or zinc blende structure.

It so happens, however, that zinc blende, ZnS, crystallizes with the same arrangement; one need only imagine one type of position as occupied by sulphur, and the other by zinc atoms. The sole change in the lattice itself is the magnitude of the distances (in diamond the cube edge is 3.35 and in zinc blende 5.39 A.). How can we explain that zinc and sulphur atoms stand in the same symmetry relationship to one another as do the carbon atoms? For the symmetry is the same in both lattices! Even the electron theory brings us no nearer the solution but makes the difficulty appear in even more acute form.

The existence of the lattice with its unconditioned and mathematical significance is very illuminating and clear, with the result that one could postulate it even without proof, and in fact it had been accepted by mineralogy before it could be confirmed by X-rays. The internal structure of the atom, however, is not part of the structure of the crystal, which is built of atoms and not of their constituents. With the atom the crystal realm is closed, the atom appears in the crystal as the last, indivisable unit. It is only by mistaken conceptions that difficulties are produced. In the crystal the atoms really are "atoms" (indivisible and smallest particles without properties) and they are not complex formations. When we investigate the atom we stand outside the crystal realm and we must necessarily find a new structure because there is no end to the structure of bodies. But just as we must group together as a unit electrons and nucleus in order to understand the atomic structure (it is in the nature of the world of bodies that they are composite, too), we must not try to include the atomic structure itself when explaining crystal structures.

From this point of view (that the atoms really are final units in the crystal) it follows almost automatically that one can not ascribe to them a certain symmetry once and for all (this would be involved if one assumed electronic movement as cause for symmetry considerations). Actually experience shows, too, that the symmetry of an atom, as far as it appears in the crystal, can change at random.

In the atom there may lie latent all degrees of symmetry as possibilities, and the one which is to be realized in a crystal is not determined by the atom but by the lattice. The lattice evokes in an atom the symmetry which corresponds to it. In other words: the lattice only ascribes to the atom a certain symmetry. This means that the cause of the atomic symmetry in the crystal is not the atom but the lattice!

As an example the sodium atoms form a face-centred cubic lattice in sodium and in rock-salt crystals but the lattice is trigonal in the sodium nitrate crystal. (Fig. 28, p. 102. Calcite structure, the lattice type in which sodium nitrate crystallizes: in place of Ca one must imagine Na and in place of CO_3 the radical NO_3). If it were possible to determine the lattices of lower symmetry classes it would undoubtedly emerge that the significance of atoms varies freely from cubic up to triclinic symmetry, according to the postulates of the lattice. If potassium, which is very closely related to sodium, and which forms a face-centred cubic lattice in sylvine, is contained in mica, which crystallizes in monoclinic plates, it must have accommodated itself to the monoclinic lattice and must in all probability show a symmetry lower than cubic. It may of course be mentioned that in the cubic symmetry all others are present. It is necessary only to stand the cube vertically on one of its corners, *i.e.*, with the body diagonal vertical, to obtain a trigonal form, in fact the exact mean between a steep and a flat rhombohedron.

(Actually one can be obtained from a cube by stretching and the other by compressing the space diagonal). In the same way all other symmetry relationships are contained in the cube. In fact one could say: since the sodium atom possesses cubic symmetry, then it possesses also all other symmetry. Is there any reason then to speak of the symmetry of an atom (*e.g.*, the sodium atom) in a crystal? Would it not be simpler to ascribe cubic symmetry (and thereby every symmetry) to every atom? But we are dealing only with the determination of symmetry which a certain atom possesses in a certain crystal lattice. And it is this symmetry which changes with the lattice and is not a permanent property of the atom.

Thus all calculations on symmetry are nothing but projections of lattice relationships into atoms—that is, the structure theorist determines the atomic symmetry not by starting from the atom but from the lattice, and therefore confirms our idea that the lattice, and not the atom, is the determining factor.

The crystal realm gives us no aid in ascribing a certain shape to the atom on the grounds of its symmetry —or we must admit that the shape can alter in the same way as the symmetry, *i.e.*, that it does not adhere to the atom at all but is caused by the lattice. The atom, if we must assume some sort of shape is represented in the crystal as a sphere which contains in itself all degrees of symmetry but yet does not allow one to appear directly in the structure. (In the cube the cubic symmetry would be especially pronounced, but not in the sphere). Atoms in the lattice lack all properties, even that of symmetry. The only spatial property which one might assign to them is that of a certain size which would enter directly into the lattice symmetry. But it is just this property which does not convey much because according to the atomic theory the heaviest and lightest atoms (with one to ninety-two electrons) are of the same order of size (in that the electrons with increasing number crowd more and more closely round the nucleus).

This then is the appearance of the crystal when viewed from within, from the point of view of its own mode of being. It is the purest manifestion of mathematics and does not allow matter to appear in any way. The crystal, regarded as absolute crystal, is a pure mode: the mode of being of the inorganic. Only in the crystal can we recognize the pure form of the inorganic, since its mode appears directly and unimpaired nowhere else.

The purity of the mode being in the crystal is by no means equivalent to the independence of its shape. On the contrary its shape is by itself not explicable. It appears in full clarity, but the reason for its existence is not shown by it. Its own mode of being gives permanence to the crystal, but it is unable to give to it existence itself. No mode gives rise to being; the being is only a manifestation of the mode. A mode of being creates no thing, not even a crystal. The thing can be found preserved and hidden in the mode but it must have originated from another source. The mother of being is substance, the father of the inorganic is space. The pure mode, be it the crystal (space), life (time), or idea (consciousness) does not contain substance, and therefore cannot create actual being. Substance lies outside the pure modes.

In the crystal the mineral (the chemical compound) is the matter from which it has originated, and from which it derives its existence. The diamond crystal needs carbon in order to exist. If there were no carbon it would not only have no existence as a tangible, sparkling crystal, but neither could the invisible lattice have existence. For even the lattice itself is unable to create the mode (the space) from itself, but derives it from matter. Within the carbon the diamond crystal slumbers, until space awakens and unveils it as lattice.

That crystal structure is determined by matter is clear and self-evident to every mineralogist. If at times the same chemical compound crystallizes differently under different conditions (*e.g.* at certain temperatures) so that not only the habit but also the symmetry is altered considerably, we must assume a corresponding change in the subtance itself.

The orthorhombic and the monoclinic sulphur crystals originate from two modifications of this element (yellow and brown sulphur). The chemical compound TiO_2 (titanium oxide) is trimorphous and occurs in three forms: as brookite, which is orthorhombic, as rutile and as anatase, which are both tetragonal but crystallized with different lattices. Chemically we are dealing in the three cases with the same compound; mineralogically there are three different substances, each of which has its own lattice. Particularly interesting is the rearrangement of leucite. It crystallizes apparently with the cubic habit of a perfect icositetrahedron, whose internal structure, however, does not agree with its outer shape, but appears to be a complicated twinned form of tetragonal (?) individuals. If this crystal is heated above 550°C. its structure also becomes cubic. At lower temperatures it is again inverted with a corresponding drop in symmetry. In this case, too, the reason for the change in lattice must be a change in substance. For the lattice can originate only from the forces of the substance. If it were due to heat alone it would have to change continuously with temperature.

Apart from such abrupt changes the relationship of crystal structure to matter appears perfectly clear. It can be concluded with certainty from the crystal shape alone without reference to its other properties that a monoclinic, orthorhombic, trigonal or hexagonal individual can not be gold or silver, and a cubic crystal can not be gypsum, calcite or quartz. For every substance has its own determined form in which it crystallizes. At times the same mineral can occur in different crystal shapes. In this way potassium felspar, $KAlSi_3O_8$, can show monoclinic symmetry, (in orthoclase, Fig. 43) or triclinic (in microcline), but it is not certain whether the orthoclase is not merely a submicroscopically twinned microcline.* Should this not be the case, it would definitely represent different substances, as, for example, calcite (trigonal) and aragonite (orthorhombic) which, although they are of the same chemical composition, $CaCO_3$, are by no means the same substance. How different are the properties of diamond and graphite (even in their crystal lattice), and yet both of them are carbon!

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*Tertsch. "Einführung in die Mineralogie", p. 40.

Phenomena of this kind prove only that matter is not exhaustively defined by its chemical composition, but they do not contradict the undoubted relationship between structure and matter.

How very sensitive crystal shape is to changes, particularly in the composition of matter, is shown best by the so-called "isomorphous series". Such a series is formed, for instance, by gold, Au, and silver, Ag, which both crystallize with a face-centred cubic lattice, in fact with almost equal cell dimensions (in the case of gold the cell side is 4.08, in the case of silver 4.06 A.). These two elements can now be mixed in all proportions, and can form one uniform crystal whose matter represents a mixture of $x\text{Au} + y\text{Ag}$. Starting with pure gold we can, adding more and more silver, pass on to pure silver, and can represent every composition in one crystal (*Continuous isomorphous series*). Actually continuous series are much rarer than discontinuous ones, for in the latter beginning with one of the components, there can be only a limited addition of the other component, if a homogeneous crystal is to result. It is important, however, that the mixed crystal must always be intermediate between the two pure crystals in material properties, *e.g.*, density, elasticity, light refraction, etc., and in its crystal shape. It may be shown by measurement of angles, for instance, that the mixture approaches one or the other constituent according to the composition of the mixture.

Matter itself is not completely described by chemical composition alone, but can, with unaltered composition, be changed considerably by outside influence (temperature, pressure or even mineralogical surround-

ings, e.g., the powers of other solutes, etc.). Chemical matter has no uniform, pure mode of being, but is always an interpenetration of different modes and for that reason it is subject to an unlimited number of new influences and inclusions. This is always accompanied by a change of its own "momentary" character. Pure modes alone can be unambiguously understood, *i.e.*, in the realm of space, only the crystal structure. Since, however, the lattice is an immediate reflection of the character of these substances, one can derive from it an immediate conception of the state of matter: substance does not change if the lattice remains unaltered. It will be shown in the next part of the book that the outer shape, the habit of crystals, can not be taken as a reliable guide for the substance.

The question now arises: is not the exact dependence of the lattice on matter a contradiction of the fact that matter is no longer present in the lattice? For the idea of an absolute and purely mathematical significance of the lattice must be adhered to definitely, if one is not to lose the crystal itself as a clear conception. The lattice is determined entirely by matter, and yet nevertheless it is part of the character of the lattice that it does not contain even a trace of matter. Every possibility of influencing the lattice is denied to it. The lattice, as soon as it exists, is strictly unapproachable to every outside influence: it is completely closed. The crystal lattice is concerned solely with itself and is parted permanently from all other being. It is a pure mode, of which there are only three in the whole universe: crystal (space), life (time), idea (consciousness). Life and idea, however, are not excluded from the world of interrupted being, but attract the latter and elevate it into their own sphere, from which it is released only with difficulty. The crystal, however, is closed strictly, and every lattice is an isolated point in the universe. The lattice is a peculiar conception of just the same accuracy as mathematics, which itself has no relation to outer being. In fact, geometry itself is to be understood as nothing but the interior of the lattice—its unity is a reflection of its interior. The basis of geometry is the crystal lattice. If there were no crystals in this world there could be no geometry. Mathematics may appear unfamiliar in its lack of relationship, but the crystal is even more puzzling, for the lattice also has its exterior, and at this point matter necessarily appears. Outside it is tangible matter, whilst the interior is pure mathematics. This is the unique character of the crystal. From the outside no influence can enter the interior; the crystal is a hermit in the strictest sense.

How can matter create the lattice since it is completely cut off from it? Once a lattice exists, every influence is excluded, the matter is no longer the mother of the lattice, but has a foreign being like everything else. The lattice can not be supported by matter, still less can it be fed. As a pure mode of being it is derived solely from itself; but, since the crystal is still able to grow it must still be fed, or at least it must at one time, at the first moment of crystallization, have been made by matter. As long as it is contained in matter and is directly fed by it it is no lattice—but as a lattice it is no longer the child of its mother, for as a lattice it can have no mother at all but only a father—pure space—which it represents with its own symmetry and with which it is identical. The moment when the lattice is released by the mother and becomes identical with the father, *i.e.*, when it parts from matter and takes up its own mathematical mode is quite inexplicable. Matter is its origin, but as a mode of being it is identical only with itself. Within matter it could lie only as a possibility, not as a real mode. As a mode it could never be born at all. The interior of the lattice is the pure mode, the exterior is matter which has been interrupted in various ways, and between the two there exists no transition and no continuity! The moment of creation can never be stated, the creation itself is unimaginable. There is no link between matter and lattice. Every type of mediation would be a process of time, the crystal, however, is a purely spatial formation and lies completely outside time. Within the crystal time can not appear in any way. For this reason there may, on the one hand, be growth of the crystal—this concerns only its material exterior—but there can be no creation of the lattice. The lattice itself is not created, it is the pure mode.

Karl Faigl, in his book "Ganzheit und Zahl"* has introduced the term isolation. According to him all mathematically representable processes are capable of isolation, *e.g.*, the motion of two mass centres which is determined by Newton's law of gravitation. If the size of these masses is known as well as their original velocities their motion has been defined by the mathematical formula for all time. If, (*e.g.*, by the action of

*Jena, 1926.

a third body), a disturbance of the motion takes place the same law will again hold after the disturbance has passed; the same formula, although the motion has changed. From the motion itself the past occurrence cannot be recognized. "The specific nature of the past is extinguished. We can say the process is without history". The same isolation that he finds in time he finds also in space. "All that occurs outside the limits of an element of space is irrelevant in its specific nature to happenings in that element of space. The role of the wider surroundings can be replaced, as far as concerns happenings within the element, by the state of affairs at the boundary of the region. If I determine this, what is happening outside the region is irrelevant as far as concerns happenings within it."

The crystal is undoubtedly isolated, but when we regard it only as crystal, *i.e.*, as a lattice, its isolation is much stricter than that of any mathematico-physical system. The crystal does not even have a boundary condition which might differ from the state of the interior and in which the influence of all the surroundings might be presented within a narrow zone. In the perfect crystal all points are completely equivalent whether on the surface or in the interior, and there is no difference in condition.* The point nearest to the surface is no more concerned with the exterior world than the central point, *i.e.*, the first point of crystallization. Every point is separated absolutely from the whole of spatial being outside the lattice, and that is why the crystal as such is absolutely isolated—whilst physical systems can only be described as relatively isolated. There is therefore no transition between uncrystallized and crystallized matter; the surface of the crystal is defined just as clearly and unambigiously as its interior, and it is completely isolated from the surrounding matter.

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*If for some reason the layers near the surface are differentiated from the interior of the crystal then such difference is part of the history and therefore not part of the character of the crystal.

The spatial isolation of the crystal is expressed most clearly in irregularity of its formation, which may be observed frequently. As a material object the crystal, as much as any body, is subjected to various outer conditions. Its formation is often interrupted, the lattice is displaced. After this, however, it starts again completely unimpaired and with its own orientation, without regard to the shape already present. One plane is divided from the other with clear-cut edges, frequently inclined only very little to one another, but nevertheless clearly divided with mathematical accuracy. On closer examination the surfaces often appear as combinations of fractured pieces which can be recognized readily when they reflect light. Even if the difference in direction of these small fragments of planes is only one of minutes or seconds, the crystal (as far as the lattice exists within it) can never have curved planes. For curvature is transition. If there is curvature, one particle is related to the next and has an orientating effect upon it. But the crystal is not continuous, it is absolutely discontinuous. The orientation is determined only by the lattice and not by the crystallized matter. A fracture of the lattice is a fracture of the crystal: the crystallized matter is not orientated to the newly-formed lattice by curvature of the plane, but the original lattice is now ignored. The new fragment is a new crystal. The faces of some crystals (*e.g.*, of quartz, and particularly those of mimetic crystals such as microcline and perovskite, viz., Chapter VI) are defined with absolute clarity, are more or less regularly striated and are composed of a thousand face fragments of smaller crystals. Every minute crystal—it may be of microscopic size—is a new beginning, a new lattice. It is as though the lattice had oscillated during the whole growth of the crystal. Shape and faces are not continuous but interrupted.

The same spatial isolation which is shown with such clarity by the interrupted formation of areas must also hold for completely unimpaired growth, for perfect formation of crystals. Even in the purest plane of the lattice in the interior of the crystal one particle does not know of another, nor one atom of the next atom. Each is isolated, each a beginning—or the centre, as this is the same—of its own crystal. One can know the other only as matter, not as lattice points. But the lattice lies outside matter and the particles obey only the lattice. The lattice guarantees the order and creates it anew with every particle. Seen from the exterior, from the material aspect, even in the completely undisturbed crystal a new crystal begins with every atom, viewed from within, it is only a confirmation of the prevailing lattice. The interruption of the lattice, however, by irregular growth is no more and no less puzzling than the fact of the lattice itself. For every new beginning is merely a new position of the lattice.

How then can we explain the first appearance of the lattice? A transition from substance to lattice is impossible. Between matter and lattice there can be no connecting link, for this link would have to be operative within time. But time exists, even in the interrupted mode, only for matter and not for the crystal. The lattice involves an important discontinuity from matter. Up to the point of formation of the lattice time has importance in conjunction with matter; after that, time has no significance. The lattice cannot originate from matter but it corresponds to it. There is a discontinuous change of matter into lattice, from the world of time into absolute space, and an intermingling of modes. The arrangement of the lattice is an isolated process in space and time.

CHAPTER FIVE

CRYSTALS AND THEIR SURROUNDINGS

The Habit

IN the real world there are no discontinuities. Even the crystal has no isolated existence within it, but is in constant exchange with all matter. The crystal, as an empirical shape, is necessarily subjected to changes—it grows and wastes away, it appears and vanishes, it breaks and heals: one might say that it lives. But it betrays imperfection, at least to the same extent as all living matter. It exhibits fractures, inclusions and impurities, irregular faces, and accidental faults, even defects contrary to its own law of structure. Numerous measurements have shown that even angles between faces, the most characteristic attributes of the external appearance, show to some degree a lack of constancy, due to the influence of external conditions. Crystals of the same locality show smaller discrepancies than those of varying origin, for in the case of the latter variations from normal may amount to several minutes.

In spite of this there is no doubt that there is a strong element of constancy underlying the conception of the crystal, and this idea of constancy is necessary for a true apprehension of matter in general. Obviously it will never be possible to allot all levels and combinations *of matter to their respective degrees and modes of* being, but the more clearly anything approaches an ideal mode, the clearer do its general relations appear. An example of interrupted being is already exhibited by the outer appearance of the crystal, the habit. The lattice shows a pure mode, the habit a penetration of the crystal into its environment. In the following we shall disregard all accidents and faults and retain only the perfect crystal as a basis for our observations. But even then its habit, composed of faces obeying the strictest laws, can no longer be described as a representation of the pure mode.

So far we have considered crystals from the point of view of their lattices, and we must now pay attention to their outer appearance. The simplest plan is to begin with the orthorhombic crystal, whose proportions of symmetry occupy a roughly central position amongst crystal systems.

The orthorhombic form has three different axes which are mutually perpendicular to one another. Its simplest form is a retangular parallelopiped. (Fig. 5, p. 64). Each of its six faces is parallel to two axes and is intersected at right angles by the third. The faces are all rectangles, congruent in pairs, and each pair is crystallographically equivalent. Such pairs are called *pinacoid faces*. The intercepts *a*, *b*, *c*, on the axis are the main parameters. The size of the crystal is immaterial, and only the relative proportions of the intercepts are characteristic. This means that the planes may be moved freely parallel to themselves without altering their crystallographic significance, as long as the relative parameters ($a:b:c$) remain unaffected. The ratio may be expressed equally well as $ma : mb : mc$ as in the form $a : b : c$. A face of the parallelopiped is therefore determined with complete crystallographic clearness by the fact that it is parallel to two axes.

By *prism faces* are to be understood such faces as cut two axes and lie parallel to the third. In our example this gives us a vertical prism originated by planes which cut the original parallelopiped faces in vertical lines through the centres of the faces. (Fig. 19; the shaded rectangle). This plane is parallel to the z-axes, and cuts x and y at unit distances (a and b respectively). It is easily seen that these four planes of the prism form a verticle column with a rhombic section, and from this is derived the name of the crystal system. (Fig. 20; the original parallelopiped is dotted). In exactly the same way prisms can be formed horizontally, *i.e*, parallel to the y- or x-axes. Prisms may equally well be formed which make intercepts on the axes of some simple multiple of the unit intercept.

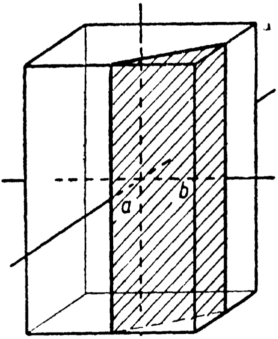

Fig. 19. Prism face.

The third type is the *pyramid face*. It is defined

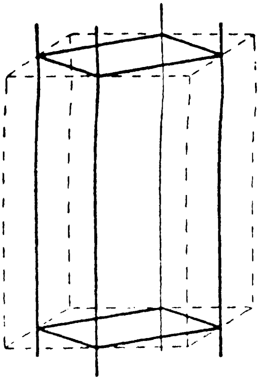

Fig. 20. The prism face (110) of orthorhombic symmetry.

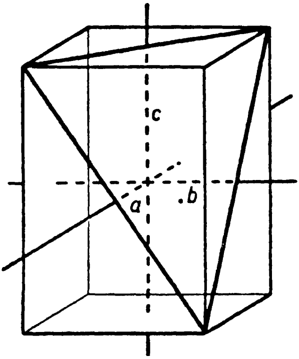

Fig. 21. One pyramid face (111) of the orthorhombic system.

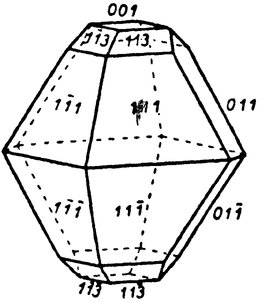

Fig. 22. Sulphur crystal.
From Tertsch, "Einführung in die Mineralogie".)

as that which makes finite intercepts on all three axes. In Fig. 21 one plane of the unit pyramid is shown. In this third type other pyramids also may be formed making more than unit intercept on any or all axes.

It is obvious that prism and pyramid faces can be moved freely parallel to themselves, for their crystallographic significance is not determined by the absolute but by the relative values of the intercepts on the axes.

Fig. 22 illustrates the various types of planes of an orthorhombic sulphur crystal. It shows the basal plane {001}, the prism {011}, the pyramid faces {111}, and the general pyramid {113}.*

The geometric boundaries or outer form of the crystal are to the casual observer the most obvious characteristic of the crystal. Actually it is just precisely the shape which represents not the essence of the crystal but its intermixture with its surroundings. The pure element, free from every foreign influence, is found only in the lattice. The lattice, however, represents the geometric order, and must be imagined as infinite in extent. If the theory of the lattice as "filling infinite space" holds, then it must follow that the lattice recognizes no boundary and cannot determine the outer shape of the crystal. Fundamentally, there are an endless series of planes within the lattice, which are of very different significance. The most important are without doubt those which would form the pinacoid faces, as for instance the cube faces of rock-salt. In actual fact crystals are often bounded by pinacoid faces only. Rock-salt crystallizes in cubes, apatite in hexagonal prisms, needles, or plates. The pinacoid faces in lower classes of symmetry must be chosen with a certain measure of arbitrariness. Thus in the monoclinic or triclinic systems we are free to choose between many possible edges for the fixing of the crystal axes. The planes are given their significance according to the axes chosen. The same plane, according to the choice of the axes, may become a pinacoid or prism face, and in a triclinic crystal, for example, we have, as long as the lattice remains unknown, no guide to the orientation of the crystal apart from the parallelism of the planes. But even a knowledge of the lattice may not enable us to deduce or predict the crystal faces which actually occur. In a cubic holohedral structure we know as a matter of course that cube faces are possible, but whether they will be shown by a crystal is determined simply by experience, and not by knowledge of the lattice. Rock-salt usually occurs in cubes, but other forms are found such as the octahedron and rhombic dodecahedron. The addition of small quantities of urea to an evaporating solution of salt causes crystallization in octahedra instead of cubes. (Fig. 23.) The lattice remains unchanged, but the mere presence of this substance suffices to alter the crystal habit. This means that growing crystals in nature, despite an identity of substance and lattice, can exhibit a variety of shapes, according to the conditions. Diamond does not crystallize in cubes, but in octahedra, which would seem explicable from the lattice. But we could not have predicted from a knowledge of the lattice that it also occurs in other forms, *i.e.*, as hexakisocta-

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*We can dispense with an explanation of "indices" (001, 111, etc.), since we are not giving an introduction to crystallography.

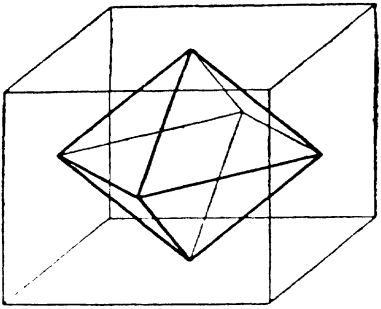

Fig. 23. Octahedron (pyramid of cubic shape).

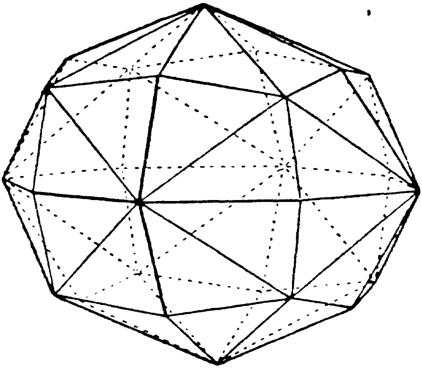

Fig. 24. Hexakisoctahedron with 48 faces.

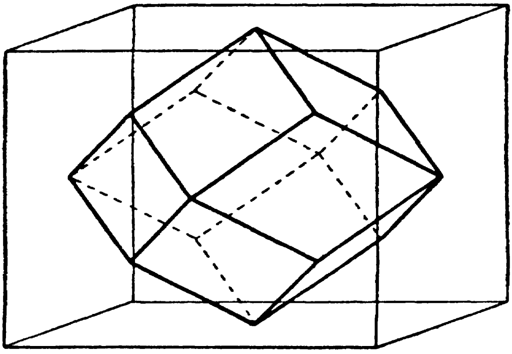

Fig. 25. Rhombic dodecahedron.

hedra (Fig. 24). Zinc blende, which has the same lattice, normally shows a tetrahedral habit, but may crystallize as rhombic dodecahedra, *i.e.*, with prism faces of the holohedral class (Fig. 25). Galena, PbS, which has the same lattice as rock-salt, crystallizes in cubes or octahedra, or combinations of both forms

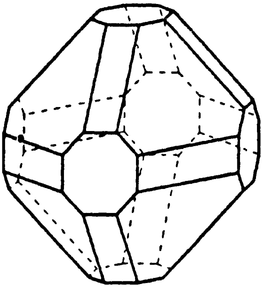

Fig. 26. A galena crystal.
(An octahedron modified by a cube and a dodecahedron.)

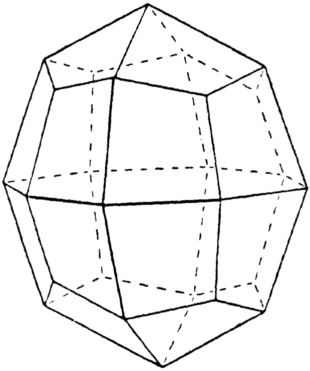

Fig. 27. Icositetrahedron.

(Fig. 26), and other forms also occur. According to Tschermak no less than five different triakisoctahedra, twelve icositetrahedra (Fig. 27), and three hexakisoctahedra have been recorded. Calcite shows an even greater variety of forms. Its lattice is a steep rhombohedron (Fig. 28). It cleaves into flat rhombohedra and often crystallizes in scalenohedra and many other combinations of forms.

All these facts show plainly that the crystal habit cannot be regarded as the external appearance of the lattice. Between the lattice and the crystal form appears a new factor, which, in conjunction with the structure, determines the habit. It is the non-mathematical environment, which meets the mathematical structure at the surface of the crystal, and the outer appearance gives only a partial reflection of the internal structure.

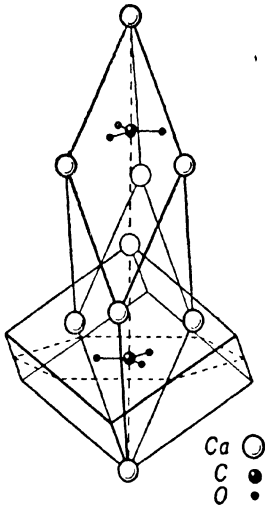

Fig. 28. Cleavage rhombohedron and unit cell of calcite. (From Ewald, "Kristalle und Röntgenstrahlen".)

When considering habits, we must distinguish between two aspects: (*a*) the type and number of faces, and (*b*) their relative size. One type of plane may appear by itself or in conjunction with one or several others. In such a combination of forms the relative size plays an important role. Between a cube and an octahedron are all types of cubo-octahedra (Fig. 29). A cube whose corners are bevelled off by octahedron faces has quite a different appearance from an octahedron with small cube faces. Nevertheless, in each case only these two types of planes occur.

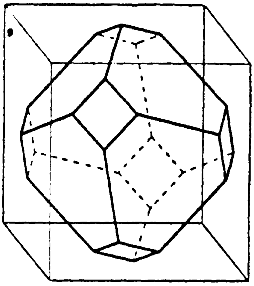

Fig. 29. Cubo-octahedron.

The habit of crystals is subject to many changes. One and the same crystal in the course of its growth may assume different forms. A living organism grows through intussusception, *i.e.*, by the incorporation of nourishment in its interior, but the crystal on the other hand adds matter to its existing faces. Usually such addition takes place at different speeds in different directions; one face may advance faster than another, and under certain circumstances an octahedron may assume a distorted shape. In this way certain faces may disappear entirely, and new ones appear. A crystal may reveal its history by a nucleus differing in refaction, transparency, or colour from the layers which were added subsequently. There are some calcite crystals whose nucleus shows a different rhombohedral form from that of the final crystal, (Fig. 30), and some barytes crystals, now in the shape of vertical prisms, reveal a past of tabular habit. (Fig. 31). Fluorite crystals often exist as cubes with octahedral nuclei.

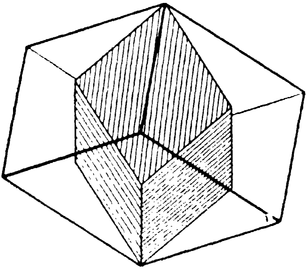

Fig. 30. A calcite crystal with two phases of growth.

(From Tschermak, "Lehrbuch der Mineralogie".)

In all these cases the substance is the same and the lattice unaltered. What has changed is due to the effect of the surroundings, the conditions under which growth has occurred. A difference in outer condition calls for a difference in habit. Nevertheless it is true that the

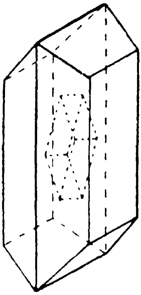

Fig. 31. A barytes crystal with two phases of growth.

(From Tschermak, "Lehrbuch der Mineralogie".)

habit is not independent of the lattice. A crystal can be bounded only by faces which conform to the lattice. A cubic structure does not permit an orthorhombic or trigonal form, but only a cubic. In spite of this the lattice is not answerable for the particular habit. It sets only the limits within which the habit may vary. The lattice decides which habits are possible, the environment decides which of these possibilities can be realized. This is undoubtedly the principle which decides the formation of crystal shape.

At present it is impossible to give a comprehensive rule which could determine the possible limits of habits according to the nature of the lattice, for the data of structure determination are still very limited. But that such a law must be assumed is shown by an empirical law which was formulated long ago in descriptive crystallography. Admittedly, the so-called "law of rational indices" refers only to single crystals, but it shows how all possible faces are interrelated in such a crystal. For on a crystal only such faces are possible as can be deduced by rational coefficients from the parameters of an arbitrary plane corresponding to a pyramid face intersecting all three axes. If the original parameters (intercepts a, b, c) are denoted by 1—the principal pyramid is thus (111)—the indices of all possible crystal faces become small rational numbers.

The same relationship between faces is illustrated by the zone law. A "zone" is composed in crystallographic nomenclature of faces with parallel edges. Every crystal has several zones. The law states that at the intersection of two zones a face is always possible.

If all zones and their intersections are found, then all possible faces can be predicted.

The law of rational indices or the zone law enable us to regard a given crystal as a potential "full form". Little reality can be attached to this "full form", and the relative size of the extant faces remains undetermined. The real crystal is normally only a partial realization of its ideal mathematical "full form". It is this abstract "full form" of a crystal which can be determined by the structure without ambiguity. The fulfilment of the schema, *i.e.*, the realization of certain faces of a particular magnitude, is not determined by the structure but only by special circumstances of the environment.

The theoretical "full form" of crystals was found merely by recording the faces which actually occurred. All the possible habits for a certain lattice must be capable of deduction from the relationships of that lattice. The possibility of all habits which appear for instance in galena must have been lying latent in the lattice beforehand. Naturally the full range of habits permitted by the lattice is much more comprehensive than the faces on a single crystal, even if perfectly developed, since the lattice allows for a number of different shapes. To find a law including all these possibilities an unlimited research into crystal structures would be required. Once a sufficient number of lattices of all or even most symmetry classes are known, a comparison of lattices with their corresponding habits should result in some formula which could elucidate all habits. Once such a generalization is found it will be possible to understand how the lattice has been interrupted where the crystal meets its surroundings, and this would mean that the pure mode of the inorganic would have revealed one of its greatest secrets, though not itself. For at these places of contact between crystal and environment it becomes self-evident that the different modes are interlocked and by their mutual interpenetration they constitute the outer being. Nevertheless the exact process is remarkably mysterious and we can scarcely grasp how it happens, or even how it is possible.

The crystal habit is open to an infinite number of possibilities. But nevertheless their range is mathematically strictly limited. Not every geometric or even regularly-formed body can occur in crystal form.

Since the time of Plato five shapes have been distinguished from all others and have been termed "regular". These are the cube, the octahedron, the tetrahedron, the regular pentagonal dodecahedron, and the icosihedron with its twenty faces. Two of these five, namely the twelve- and twenty-sided ones, have never been found in the realm of crystals, and never will be found, for mathematical theory shows that they are impossible as crystal shapes. Admittedly some minerals crystallize as pentagonal dodecahedra which are terminated by twelve congruent but irregular pentagons. It is the regular pentagonal dodecahedron and the extremely regular icosihedron (terminated by twenty regular equilateral triangles) (Fig. 32) which cannot occur as crystals. The reason underlying this is expressed in the law of whole numbers, and is due particularly to the fact that 2, 3 and 5 are not divisible by any one whole number except 1.* This is the mathematical background, in fact the metaphysics of crystals. It is numbers which prescribe possibilities in the crystal realm and which impose very definite limits. "The natural numbers, however," as the mathematician Kronecker says, "are made by God."

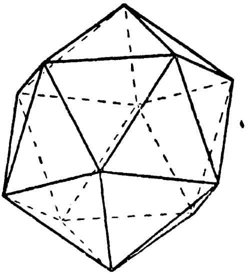

Fig. 32. Icosihedron.

The elucidation of *cleavage* has progressed no further than that of habit. In fact, cleavage is understood to a rather lesser degree. For the habit can at least be explained for any one crystal as a special case in a series of possibilities. Cleavage on the other hand can only be recorded; there seems to be no principle by which it can be deduced from the crystal shape. It is certain only that the cleavage plane is parallel to some possible crystal face. Thus cleavage is used by mineralogists to determine the position of possible faces on individual specimens which show no actual faces. The direction of cleavage must undoubtedly be of singular importance, for why should the crystal break in these clear-cut planes? This cleavage plane does not always correspond to the most important type of plane, as for example to the pinacoid faces. Cubic crystals, however, normally cleave parallel to cube faces (rock-salt, galena), but sometimes there is a cleavage parallel to prism faces (zinc blende) or to octahedral faces (fluorite, diamond). There is no doubt, therefore, that cleavage and crystal form are not equivalent, and in fact there is no clear relationship at all. If in other crystal systems where several orientations are possible, the cleavage plane is taken as the most important plane it would be equivalent to assuming that cleavage must reveal the principal planes of the crystal. This assumption in most cases is unjustified and is the more questionable in that it waives *a priori* the possibility of explaining the cleavage with knowledge of the structure of the crystal. Statements concerning the cleavage of different crystals of these systems have therefore little significance, for the axes are so frequently chosen according to the cleavage. In all systems except the triclinic there are limits to the possibilities of orientation, *e.g.*, such as are due to the hexagonal axes in the hexagonal system, or to the plane of symmetry in the monoclinic system. But even in these cases the direction of cleavage follows different planes. Hexagonal crystals most frequently show a basal cleavage (beryl), but cleavages parallel to prisms and more rarely to pyramids have been recorded. Monoclinic crystals cleave parallel to the plane of symmetry (gypsum, orthoclase), or perpendicular to it (mica is a perfect example).

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*The same reason is responsible for the insolubility of equations of the fifth degree. (F. Klein, "Lectures on the icosihedron and the solution of equations of the fifth degree." Leipzig, 1884.)

There is thus no relation, or at least no simple one, between cleavage and crystal form. It is an unavoidable postulate, however, that cleavage must be dependent on the lattice, and it is here that one should find its ultimate cause. The fact that any particular mineral, whatever its habit, always shows the same cleavage (Tschermak) proves that it is not the outer world with its ever-changing conditions which determines the cleavage, but it is the inner influence of the lattice. This is the only thing (apart from the substance) which remains unchanged as the habit alters.

In a well-known example, calcite, the cleavage rhombohedron is only rarely found as the crystal form (Tertsch). Nevertheless, this plane in the structure of calcite is of such fundamental importance that different rhombohedra and scalenohedra, hexagonal prisms and plates, all the different combinations shown by calcite, cleave in this one rhombohedron with an angle between the faces of 105°. From this emerges the clear result that in calcite as well as in all other crystals the cleavage, or at least the cleavage *direction*, must find an explanation in the lattice. For only the lattice is persistent throughout all changes of form.

On the other hand cleavage must be regarded as a physical property deriving from the substance itself and not the lattice alone. Cleavage does not depend directly upon the surroundings as did the habit, but is a product of the interaction between mathematical structure and matter. The fact that the mineral shows a cleavage at all can only depend on the matter, but the direction in which cleavage takes place must depend on the lattice. If it should one day be possible with the aid of more comprehensive knowledge of structures to find a general rule according to which cleavage is determined by the lattice, it would mean that yet another deep secret of the inorganic, besides that of the final explanation of change in habit, would have been unveiled.

CHAPTER SIX

THE CONCEPT OF THE CRYSTAL

The Shape

WE have so far assumed that within the limits set by the lattice the shape of the crystal is determined by the surroundings. But here we must make a clear distinction. For how is it that the environment itself can produce a shape? In fact, what is the environment of a crystal? In this conception we may include all physico-chemical conditions, *e.g.*, adhesion, cohesion, gravity, all types of radiant energy and heat in particular, and states of aggregation with all gradations between fluid and solid. This results in a mass of conditions, forces and influences, which are all unorientated with respect to the crystal, and without mathematical harmony they all act on the crystal, and as a whole they give a background of an infinite number of conditions. Perhaps only a few of these conditions are of fundamental importance for the crystal, but even these few cannot predetermine the shape in which the crystal will actually appear. In fact, by themselves they can determine no kind of shape. Lattice and environment as we have seen are perfectly distinct, and the possibilities of shape which the lattice permits can merely be fulfilled and in no way altered. The lattice will never yield. This means that the surroundings can never be the determining but only the fulfilling factor. On the other hand, one particular shape is always chosen from all the possibilities of the full form, for the same lattice permits and actually receives all kinds of habits, according to the conditions. Does the choice then lie with the surroundings? But how can a choice take place without preconceived idea of the shape? For this would mean that the surroundings have after all created such a shape. An insoluble problem arises if the actual shape of the crystal is to be deduced from lattice and surroundings alone. The lattice by itself does not postulate a closed shape and the environment plays a quite passive role in relation to the crystal. It only fulfills the conditions imposed by the lattice. Under these circumstances it would be impossible for lattice and surroundings to produce a final crystal without the addition of a third factor. The essence of the lattice lies in an arrangement of points in planes and lines, and it rests with the environment to realize the possibility or impossibility of this order. If these conditions are given, no closed structure but merely a realized lattice, *i.e.*, the skeleton of a crystal, can result.

Such skeleton- or "lattice-crystals" (a terminology originated by Bréon) actually occur in nature and not at all rarely. If we leave out of consideration the twig-like forms of various precious metals (gold, silver and others) in which the mathematical relationship appears more or less distorted, the net-like shape of argentite shows the cubic lattice almost perfectly (Fig. 33).

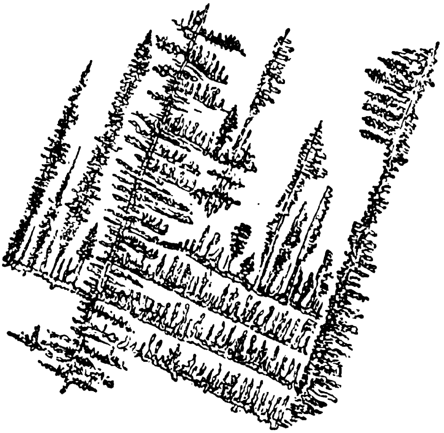

Fig. 33. Net-like formations of argentite.
(From Tschermak, "Lehrbuch der Mineralogie".)

Here growth does not occur in closed surfaces but along the lines of a cubic lattice. The enlargement (Fig. 34) shows how the small octahedra are arranged

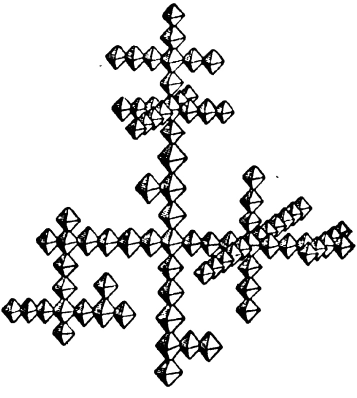

Fig. 34. Part of Fig. 33, enlarged.
(From Tschermak, "Lehrbuch der Mineralogie".)

in a way corresponding to the three major axes of a cube. Here one sees, at least by the arrangement of the octahedra, the direct fulfilment of the lattice as such without any influence from the outside. The octahedra themselves are closed forms. As such they go beyond the postulates of the lattice and show a fulfilment which is not directly conditioned by the lattice. As an example of lattice-crystals in the hexagonal system we may quote the familiar crystals of snow. They, too, represent not crystals but only skeletons restricted along the horizontal axes. (It is to be noticed how these crystal shapes always stand out in leaf-like form along the direction of an axis). It is just precisely the vertical, principal, axis which does not come into play.

Only such crystal skeletons, and not closed shapes, can be explained by lattice surroundings alone. The lattice prescribes the orientation in straight lines and the surroundings furnish the substance passively. The result is in no way a crystal because nothing has been able to determine a habit.

Furthermore, these skeletons, *e.g.*, the snow crystals, do not illustrate at all the relations which exist in a real crystal. For crystals are built not along axes, but along planes as is shown clearly by cleavage and the layer-like addition of matter during growth. Since a crystal can be broken up along cleavage planes into as thin plates as we please, it is quite clear that the axes are not directions which are in any way favoured. Only the lattice itself with its planes and variety of directions has any real significance. There are no definite axes which must intersect exactly at the centre of the crystal.

In fact neither real crystal nor lattice possess a centre at all as a distinguishable point. For the lattice is infinite and in an actual crystal all points are equally equivalent whether on the surface or inside. The true crystal is thus necessarily built in a different manner from the way which these skeletons might suggest. In the latter the relationships seem distorted and falsified because, owing to the lack of a closed form and fulfilled lattice-planes, the axes must serve as supports for the substance. They are thus called upon to form the shape, though in a full crystal they would have been deprived of their importance. The analogy with the snow-crystals prompts us to assume that also in the cubic skeleton of argentite the directions in which the octahedra are arranged in line are not to be regarded as normal lattice directions, but as the axes of the cube. Every intersection of such areas corresponds with the centre of a cube.

It may be concluded, therefore, that the full crystal cannot be composed of lattice and surroundings alone, but that its shape must embody yet another factor. It is precisely this factor which on the one hand gives the lattice with its planes and directions its full significance and on the other confers a finite shape upon it.

This new factor appears fairly clearly in a crystal which is "healing up". The full form is only shown by an individual grown while suspended in solution. Most crystals on the other hand have grown out of a solid foundation, a matrix. If removed, their breakage will be along a more or less irregular surface, or at least will not show a bounding face. Crystals which have broken off in this way often heal up if new substance is made available at the breakage. New layers are added on one by one until even bounding faces are formed, *i.e.*, until the crystal has "healed" into its perfect form.

The process is even clearer in the case of crystal fragments which have been broken from a perfectly-formed shape. If such a fragment is placed in the requisite solution it does not grow as a fragment but perfects itself again until it becomes a complete crystal. The crystal fragment in its new shape is orientated in the same way as the original crystal (Fig. 35). Such healing up can hardly be explained by the lattice alone. The internal structure would be fully obeyed if the newly-added portions were laid down in all directions according to the mathematical order prescribed by the lattice. The influence of the lattice is the same at all points, even on the surface. Yet the additions must have taken place more rapidly in cavities than at points which are projecting, for only in this way can a face reform and a perfect shape result. The process cannot be explained by mere mechanical considerations because in that

Fig. 35. Crystal fragment healed into perfect shape.
(From Tschermak, "Lehrbuch der Mineralogie".)

way, under the best conditions, only a plane of random orientation or a curved surface could result, according to the type of fracture; but a crystal face corresponding to the habit could never be formed. What is it then that informs the molecules of their present habit, for it can no longer be recognized at the breakage? There must be some definite will to attain that habit which can not be due to the lattice nor to the solution, which is the same at all points. There must be some underlying conception of the completed crystal which directs the fragment towards completion as in growth or healing of a living organism. In both cases the tendency is towards the shape as such. This tendency must be the same as that which gave the crystal its original habit. The shape, however, which strives to attain perfection, is something quite different from mere orientation according to a lattice.

A number of different phenomena prove that the crystal shape is formed by something more than the surroundings and the lattice, if not even in contradiction to the latter. Amongst these we might mention mimetic phenomena, *i.e.*, the apparent assumption of higher symmetry by single crystals or twinned formations.

It is peculiar that certain monoclinic minerals exhibit cross-sections which closely approach regular hexagons (*i.e.*, hexagonal symmetry), and combinations of such minerals show rhombohedral (trigonal) forms. Othorhombic minerals form apparently hexagonal crystals if the prism angle is near 60°; if the angle approaches 90°, combinations will have a tetragonal appearance. Higher symmetry of that sort in a simple crystal may be termed pseudo-symmetry. This seemly higher symmetry may be quite possible on the basis of the actual relations, but it does not by any means follow logically that the final form should appear to be due to foresight. The relations in the case of quartz are particularly remarkable. Quartz belongs to the trigonal trapezohedral class. Normally it appears as a hexagonal prism with pyramid faces, that is to say as a form of higher symmetry. Frequently the brightness of the pyramid faces reveals that they are not all equivalent, but that groups of three alternate faces belong together. If the crystal is etched the resultant differing orientations of the etch-figures show clearly that neighbouring faces belong to two different rhombohedra. (Fig. 36. Notice on neighbouring pyramid faces the alternate horizontal and inclined positions of the etch-figures and their pointed ends on the verticle prism faces.)

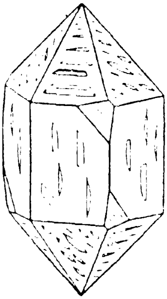

Fig. 36. Etch-figures of a right-handed quartz crystal.

(From Tschermak, "Lehrbuch der Mineralogie".)

The achievement of simulating higher symmetry and of fulfilling as far as possible the exact conditions of the symmetry appears with great clarity in mimetic crystals. They are twinned formations of innumerable small and often very minute crystals. They are complicated, artistically constructed shapes, which not only completely fulfill the higher symmetry in outward appearance but correspond almost exactly in their interfacial angles to that higher crystal-system. The miroclíne crystal shown in Fig. 37 gives the appearance of a simple crystal of monoclinic habit (at one time this mineral was actually considered to be monoclinic). In fact it is composed of many small triclinic individuals which are shown in the figure by shading which, incidentally, is far too coarse. The imitation of the monoclinic system goes so far as to allow these twinned formations to form "Karlsbad-twins" (Fig. 46). This corresponds to a twin law which has no application to the triclinic, but is characteristic of the monoclinic system. Finally, perovskite forms groups of twins in the shape of a cube (Fig. 38), in fact of the highest symmetry class, whilst the actual small crystal which creates such striking semblance possesses only monoclinic symmetry. In this case it is utterly im-

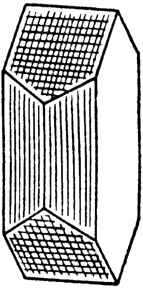

Fig. 37. Mimetic crystal of microcline.
(From Tschermak, "Lehrbuch der Mineralogie".)

possible to explain the shape of the mimetic crystals by correlation of the two systems.

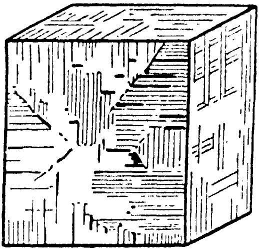

Fig. 38. Mimetic perovskite crystal.

(From Tschermak, "Lehrbuch der Mineralogie".)

The question now arises as to whether the status of all mimetic crystals can be explained in the same way as for leucite crystals; *i.e.*, whether they crystallized originally in the higher symmetry and underwent a subsequent inversion.* In such a case this would only be a proof that if a higher temperature does cause a change in structure, it usually brings about a higher symmetry. At all events it is peculiar that imitations of lower symmetry never occur at all,† although it might appear that such phenomena could occur more easily, as the real symmetry could be completely preserved. Thus a tetragonal or orthorhombic shape could be built of little cubes without difficulty. The mimetic twinning which actually occurs in crystals must always be connected with some strain, and, since a higher shape can never be formed from a lower one, mimetic twinning can take place only by simulation and by attempts to minimize the forces opposing it. If the individuals were originally separate forms, there must have been some decisive will to the higher symmetry and to suppress the real relationships, in a way which can scarcely be overlooked. That same striving towards higher symmetry must undoubtedly be present in the pseudo-symmetry of single crystals, if not so strikingly. Mathematically, crystal systems and symmetry classes are quite distinct from one another. The crystals themselves, however, show in all systems the tendency towards the highest symmetry. The entire crystal world thus shows a unity culminating in the cubic shape. One might say that every crystal desires to be cubic. This is another correlation which transcends the relations of the lattice, a thirst for a shape which is not identical with the lattice. This tendency, which can not be disputed, must be part of the character of the crystal; it is impossible for it to be a mere coincidence. It appears, however, that this tendency—as far as it appears in the imitation of higher symmetry—is related only to mathematical relationships. It is important to realize that there must be a factor which originates neither in the lattice nor in the surroundings, and it is precisely this factor which concerns the outside appearance even to the extent of contradicting the atomic structure. The shape must be some kind of idea, which, previously intended, lies beyond lattice and surroundings. The crystal does not reveal itself solely by mathematics and matter, but there is an underlying idealism.

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*Why this question has never been formulated by mineralogists, or what reasons and proofs may be advanced against such a theory, is unknown to the author.

†Regular distortions cannot count as such. They are only imperfections of a more regular shape.

The idea of shape can be demonstrated even more clearly and strikingly. Rutile, TiO_2, belongs to the tetragonal holohedral class. Its unit cell is a flat one.

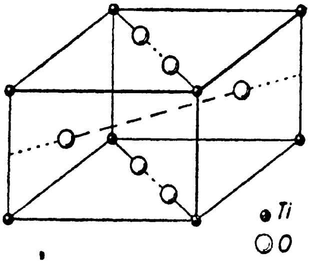

Fig. 39. Rutile structure.

The z-axis is distinctly short. (Fig. 39). In contrast to this, the crystals frequently exhibit a long, or even needle-shaped form. The fine rutile needles which are often occluded in other crystals (*e.g.*, in Bergkristall) are well known. The habit in a strict sense is bound by mathematical relationships and brings into evidence the internal symmetry, but the needle-shape more or less over-rides the symmetry relations and makes no differentiation between orthorhombic and tetragonal shape. Here again we recognize some will which strives to attain a certain independent shape. Such preconceived ideas exist in great number in all the crystal world in all classes and system. Plates, needles and prisms may belong to the triclinic, monoclinic, orthorhombic or tetragonal systems. All forms which are dagger- or stem-like, needle-like or fibrous, compact or fine as hair, all show their shape much more strikingly than their relation to their crystal system. As ideas they transcend the mathematics of the lattice and the nature of their habit. The habit is a reflection of internal relationships, the shape, however, plays freely round it. The shape, as an idea, is present in every crystal and gives it completion.

The shape, however indefinite, may frequently be of considerable importance to the scientist. In the orthorhombic system all three axes are independent, but equivalent, in that none is given any *a priori* preference. In the completed crystal shape the distant axis is the one around which the pyramid faces are grouped. And even the most untrained crystallographer would not set up an elongated orthorhombic crystal without placing the elongated direction vertically, *i.e.*, as z-axis. The fact that it is not necessarily the longest of the three shows that it is not the mathematical relations but the habit as such which gives one of the three axes preference. Mathematically speaking the orthorhombic crystal is a combination based on rectangles, and it is only the shape which gives it its elongated appearance.

The part played by the idea of the completed crystal may be recognized in yet another respect. Crystals form a uniform world of their own which is not as strictly divided according to systems as might appear from crystallography. Whilst, mathematically, the systems are clearly divided from one another, there are continuous changes so that sometimes only accurate measurements can decide to which symmetry a certain individual does belong. The monoclinic crystal of augite (Fig. 40) appears, except for the a-faces which occur only in pairs, similar to an orthorhombic, or even tetragonal shape to the point of confusion, and not every triclinic crystal shows its low symmetry so

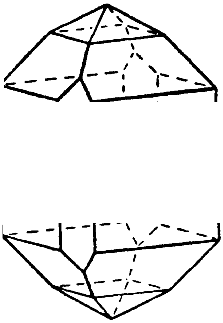

Fig. 40. Monoclinic augite.

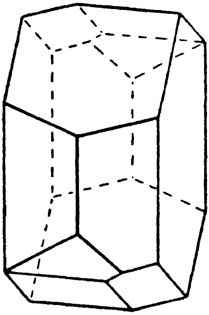

Fig. 41. Anorthite. (From Tertsch.)

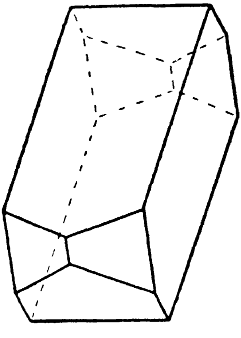

Fig. 42. Triclinic crystal. (From Tschermak).

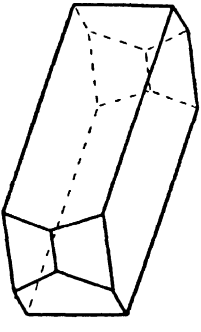

Fig. 43. Monoclinic crystal. (From Tertsch).

openly as the present sketch of anorthite (Fig. 41), which actually shows only combinations of parallel pairs of faces. Fig. 42 and Fig. 43 undoubtedly show a very similar shape and yet the first is a triclinic and the second a monoclinic crystal. They have different symmetry, but are subject to the same idea.

CHAPTER SEVEN

TWINNING

THE formation of twinned crystals cannot be explained by the lattice any more than can the habit, for twinning contradicts the nature of crystals, as far as this is expressed in the lattice alone. It is obvious at a glance that the substance plays no important role in the phenomenon, for twinning is just as mathematical as the lattice, at least more so than the habit. The habit can change its faces in the course of growth but the twin cannot change its plane.

As we have seen the crystal in its essence is "isolated" more so than any phenomenon, and its lattice is absolutely "isolated". For that reason the crystal, as far as it is a crystal, is strictly separate from the environment, and even completely parted from its own kind. The lattice is concerned only with itself and as such is unable to incorporate anything from this outside world, be it mathematical or of substance. As we have shown in greater detail, the substance is completely excluded from the lattice and every mathematical structure which does not correspond to the lattice can meet the lattice only at the surface, and it can never intrude into the interior, or even unite with it; if, however, they correspond then it does not lie outside, but is in fact identical with the lattice whilst the latter again is concerned only with itself and not with the surroundings. For that reason every crystal is always closed within itself, and the world of crystals only exists in our consciousness, but not outside it, since for the single crystal all other crystals are nonexistent. That is, at least, what the pure mode of the inorganic postulates.

But even the organic is blind (although its essence is a unit, in the sense of Spann), to the rest of the organic world, at least in the realm of time. In the present condition of the plant there may lie, according to Karl Faigl, all its past (including the existence of all its ancestors) and through the present it may indicate its future. This complete chain of individuals may continue as a closed unit in the form of a single chain through ages, centuries, and thousands of years, striving towards the future, always exemplified by one single individual and always knowing only of itself and its past, because the plant, as an organism, can never learn of its own kind and cannot even recognize its own sisters. In the seed lies summed up the whole past, and the possibility of the future is indicated; this seed grain can nourish itself only from the inorganic and thereby grow or die, but not a trace of the organic can intrude into it or the plant which sprouts from it.* The plant knows the inorganic as we know the entirety of outer being, but it is excluded from the world of the organic just as the crystal is from its own kind. For fertilization means nothing to the blossoming individual, but only to the fruit. Fertilization of two separately-sexed plants unifies two genealogical trees and the whole past of the pollinating (male), and the pollinated (female) plants flows together in the now growing fruit towards one single future, the new plant. The flowering plants, however, which together create a new future know neither about this future, their child, nor of one another. The female individual continues growing, vegetating, and blossoming in the same way quite independently of which male plant it was that produced the pollen. For the pollen does not penetrate into the plant—which itself can not be fertilized—but only into the stigma, *i.e.*, the seed-bud, and the essence of the pollen flows through the whole new fruit, which no longer belongs to the mother plant but is already a self-contained individual. At the moment of the fertilization the new plant is born and can no longer be recognized by the mother; the male genealogical-tree circulates only in the child and can never enter into the recognition of the withering mother. It is the longing of the stigma, that is to say of the unfertilized blossom (for the blossom is still a part of the flowering individual) to reveal itself to the pollen, a longing of the pollen and at the same time of the whole male individual to cause fertilization. When the pollen penetrates to the stigma it has already parted from its father, and the fruit at the moment of contact separates from the mother. There has been fertilization, but no mating, for the mates did not recognize each other and in spite of their common posterity they are just as strange to each other as though no touch had occurred. In actual fact the touching took place only between their scions, which at the moment of the touching no longer belonged to them, and not between themselves. The seed may now be freely lowered into the soil. It will germinate where it is planted, if all that which soil, air, and sun give corresponds to its wants, and the plant will grow, blossom, and flourish even if it is the only living thing on an island or within a wide region. On the other hand, if that same plant stood in a jungle and if it were pressed by crowds of exuberant life it would perceive all this only as its environment, and it would have no idea that there were plants other than itself. It experiences only a past which reached back into the dark, and glances, as a member of a well-nigh infinite chain, into a completely uncertain future. It is from here that its strength is derived, the longing draws it ahead. It is a child of time and that is why it is blind to space. It hastens at the summit of the genealogical-tree, branched in the past like a ray into the infinite future.

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*We may disregard insectivorous plants which can only rank as an exception or curiosity.

The animal as also in the case of all spiritual elements is a unit in the full sense. Animals know of each other, love or hate one another, pursue and eat one another. Animals have need of one another even if they live in enmity. An animal which could not see a second living thing throughout its life would at least be utterly unhappy and would deteriorate mentally or wither. Animals learn from each other, educate each other and increase their mutual capabilities. This is done to an even greater extent by the human being. Further, he has a living connection not only with the present, his contemporaries, but also with all the past. Neither space nor time are limits to spiritual unity. Every man stands at the centre of a sphere indefinitely bounded by space and time. The limits of unity can, however, be freely extended—in fact strictly speaking, they always extend to infinity. Every man forms the centre of a living unity; he *is*, and that is comprised within the character of the spiritual.

Man, however, also knows the union of love. Love, however, is a recognition. Only by recognition is the subsequent fate possible. For man, love is possibly less a longing for the child than for the personal destiny. From love there emerges not only the child, but actually the fate of each partner. In plants bride and bridegroom never know each other, in the case of man they unite and have communion with one another, so that they become each other's fate—be it for happiness or misfortune—and form an indissoluble unity. He who can exclude the loved partner from his inner being has never loved at all. It is the deepest good fortune and yet also a great grief for mankind that two beings can have knowledge of one another.

The essential nature of the spiritual is to be open to all, that of the crystal to be closed to all. The crystal in all its strictness, as it appears in the lattice, can recognize nothing but itself, and in particular is ignorant of its own kind. For every contact of two crystals means a fracture in both. The lattices are completely non-elastic—they do not make an approach to each other as do animals which do not as yet know each other, but break off abruptly—or they are from the first moment of their existence not divided, but joined as one. This is the case in the twin.

One must be clear that twinning is without parallel in the whole of outer being. All sorts of union in the plant-world and in animals (including mankind) never have this extraordinary phenomenon, to whatever extent their nature may at times be disturbed or even destroyed. For all living matter is able to open itself, the crystal can not. Only in the broken state (the region of adhesion) can the inorganic intrude into itself and mix itself. The colloidal state, particularly in the case of gels, shows the highest degree of capability of fusion—and yet it is far removed from what takes place in the shade and intimacy of spiritual devotion. But that the crystal should open itself and should unite with another, completely contradicts its character, and destroys the concept of the lattice as an absolute mode. Certainly, there are never two originally separated crystals which have grown towards each other and penetrated after touch, "but they grow in such a way that even from the very beginning they appear as a double individual" (Tschermak). But even in this form the phenomenon is completely inexplicable and in entire contradiction to the nature of the lattice, as only the lattice and not different substances twin with one another.

Contact and penetration twins may be distinguished. Contact twins are formed for example by the monoclinic gypsum crystals. The two individuals join along the "twin plane", *i.e.*, along a possible crystal face, in this case the face (100), in such a manner that the plane of contact is at the same time the plane of reflection (Fig. 44). The two crystals, therefore, are in exact symmetrical relation to one another (as an object and its image). If one half is turned through

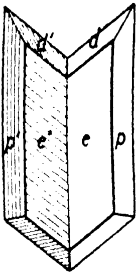

Fig. 44. Swallow-tail twin of gypsum.

180° about the twin axis (*i.e.*, a line perpendicular to the twin plane, the twin axis in our case being horizontal) so that top and bottom are interchanged with the plane of contact unaltered, it is congruent with the other half and can be regarded as its continuation

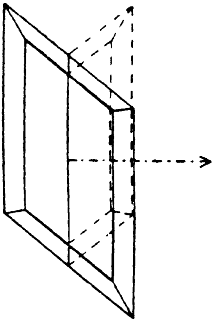

Fig. 45. Relation between single crystal and contact twin.

(Fig. 45). Purely mathematically one could imagine the twin made in this way from a single crystal by turning one half through 180° as compared with the original position. Something similar is actually present in the case of the "glide twin". Owing to the shape, however, one must in any case assume two individuals which—apart from their deformation—appear linked to each other by mutual relationships.

A complete penetrating of two individuals forming one single shape of apparently higher symmetry occurs in the quartz crystal, which we had occasion to mention above (page 119 ff.). A particularly fascinating example of partial penetration is given by monoclinic felspar (orthoclase) in a twin named after its most frequent locality, the "Karlsbad twin". It appears as a union of two congruent individuals which have penetrated deeply along the entire contact plane and which have grown in this common state into an indissoluble unity. (Fig. 46). At the same time they have crossed one another in such a way that the back faces M, and the heads (top and bottom) of the two individuals remain partially undamaged. The curious fact now emerges—that crystallographically equivalent planes of the two individuals are non-equivalent for the crystal. For the twin is only possible if the two pinacoid faces M, which are mathematically identical, appear on one crystal, as also on the other, as front

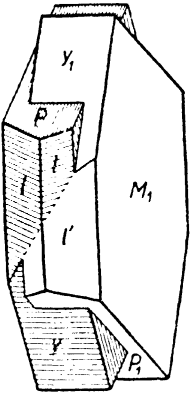

Fig. 46. Karlsbad twin of orthoclase.

and back faces. If we denote (Fig. 46) the front face as M, the back one as M′ (on the second crystal correspondingly as M_1 and M'_1), then on twinning M can only lay itself on M_1, or M′ on M_1', but never M on M_1', or M′ on M_1, although by mere parallel displacement M and M′ (or M_1 and M_1') can be made to coincide.* If the twin is to be successfully formed only front face may meet with the front face or the back face with the back face. If, however, front and back of the twin differ, then I and I′ (I_1 and I_1'), although related as mirror-images, can not have the same significance. (In order to appreciate the difference one need only imagine the faces as derived from the triclinic system, where the plane of symmetry is not present, and therefore where I and I′ do not occur equivalently). This means that the terminology of faces due to Tschermak is not strictly correct in Fig. 46. P and P_1 are not equivalent since the one must be imagined as derived from the side of I, the other from the I′ side. If they are made equivalent the difficult situation arises that in the twin the top of the first individual meets the bottom of the second and the bottom of the one the top of the other. Those faces which correspond to each other crosswise, and which mathematically are absolutely the same, are in that case non-equivalent. From whatever angle one may regard the problem the relation remains that, on twinning parallel faces of the same crystal differ in significance so that the symmetry which would otherwise hold appears broken or degraded. In fact one obtains a left-handed or a right-handed twin according to whether M is put on M_1 or M′ on M_1' (*i.e.*, front on front, or back on back; the one on the sketch represents a left-handed twin; the head of the individual turned towards us is turned towards the left). As these two twins can not be superimposed by any means and as they must be distinguished crystallographically one should for logical reasons distinguish even the pinacoid faces. For the twin is orientated according to its shape, not to pure mathematics. It distinguishes two further faces which are congruent and could (without turning) be brought directly into coincidence; from its point of view the faces have a top and a bottom (or, if these ends are made equal, a right and left). Twinning always takes place so that on touching of the two congruent, (contact- or penetration-) faces, head is superimposed on head and foot on foot, but left on right and right on left, much as in the case of two people locked in one another's arms. The sole difference is that in crystals both front and back halves can twin.

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*This changed significance of faces can hardly be demonstrated by a drawing, but becomes quite clear in models.

How should the structure be imagined in penetration twins in those parts which are common to both individuals? It can hardly be visualized otherwise than that on penetration of the two crystal structures it is formed in the same twin position as can be seen on the outside shapes of contact twins. This means that there are two intruding lattices which form an indissoluble unity (analogous perhaps to the two penetrating face-centred lattices of the rock-salt type). And this means that both lattices have their significance but with exact lattice-like relation to one another. Yet, it is not quite the same as in the case of the rock-salt lattice. For here the lattice is a single one and supports only one shape (the cube). In the twin, however, although there exists an equally strict unity, there are still two lattices woven into one another, supporters of two separate though mathematically congruent shapes. Both lattices have been absorbed in one another and yet have still been preserved. They behave spatially as do the souls of two lovers spiritually. Yet, the fact is even more wonderful in the case of the crystal, as we have already hinted, for the unification takes place merely between the two lattices and it is still a contradiction to its nature. A lattice can not possibly itself recognize another, however completely congruent. In the twin, however, the two have recognized each other. For neither is lost and neither disappears in that unity, but they touch each other in exact mutual correspondence. One knows the other as completely as itself. There can be no question of a coincidence for by coincidence it would always be impossible for the joining to be absolutely exact—as soon as it were not exactly mathematical the two lattices would have to interrupt one another and not one atom could penetrate into the other. Here it really seems as though—like animals with their feelers—they had touched one another, in order to arrange themselves accordingly. The fact that they occur twinned from the very first does not exempt them from the necessity of the first recognition, for at no time are they one lattice but always two; otherwise they could no longer emerge separately from that unity. The capability of the mutual recognition can not have been derived from themselves, for that is not in the nature of the lattice, in particular it must not be derived from mathematics, but from the shape, so far as it transcends mere mathematics. And the shape follows on twinning, as we have shown, and is curiously independent and distinct from mathematical relations. The shape must in this case be the determining factor. The idea which includes the shape must have acted as mediator between the two lattices and conveyed to them the capability to unite and mutually to recognize each other. Lattices are not interrupted spatially but ideally and have been deprived of the limits of their pure essence. They are no longer absolute lattices but lattices touched and guided by the idea when they form the twin. Through the idea they have opened and have become accessible to one another. It can be no wonder then, if the union of crystals, which otherwise appear to be well outside living connections with all other being, finds so many accords in the realm of the living. All union originates in the spiritual, whose essence is unity in multiplicity. The spiritual, however, which can touch crystals directly is only the idea of the shape. Every crystal, in so far as it possesses shape, participates in the idea. The true crystal thus is not a pure lattice (the pure mode never has real existence), but is always a lattice which has already been touched by the idea, and has thereby been made into an actual shape.

CHAPTER EIGHT

THE PERFECT CRYSTAL

DESCRIPTIVE crystallography regards the crystal from the strictly mathematical point of view, not as a lattice, but as a shape. On the basis of existing faces and edges it introduces a set of axes into the shape. If we imagine that these axes (originally of differing lengths) are made equivalent step by step, and that the angles between the axes (originally of a random nature) are converted into right-angles, we obtain as a result the different crystal systems (triclinic, monoclinic, orthorhombic, tetragonal and cubic); or by combinations of the right-angle and the angle of an equilateral triangle the hexagonal and trigonal systems result. In addition there are the symmetry elements: planes of symmetry and two-, three-, four- and six-fold axes. If all the symmetry elements are present which are compatible with a set of axes of given equivalence and given angles, the corresponding holosymmetric arrangement (holohedral) of that particular system results; by the omission of certain elements of symmetry hemihedral arrangements are obtained, which together with the holosymmetric forms, comprise the thirty-two classes of symmetry.

The fact that in order to define a shape crystallographically not the actual intercepts on the axes of a face are used, but merely the ratio of these intercepts ($a:b:c$), and the fact that by these three numbers one describes not one but a multitude of parallel faces (fundamentally there are an infinite number), must be regarded as an ingenious convention which corresponds closely to the character of the crystal as far as concerns the lattice. Of similar ingenuity is the determination of all possible faces of a crystal by zones, whereby the ideal aspect of the crystal may be grasped. Nevertheless, this magnificent system used by descriptive crystallography, however strict it may appear, is a wanton combination (if not amalgamation) of different view-points. For this reason it is unable to throw light on the real character of the crystal. As a compromise it does not in any way approach final conceptions. For instance, it permits axes of symmetry to be regarded as preferred directions and non-existent faces to be imagined possible, and thus contains a hidden contradiction and confuses the character of the crystal. For in an individual where non-existent faces are considered as possible, preferred directions are unthinkable. In actual fact every crystallographer knows that particles in a crystal do not necessarily arrange themselves according to the axes and to their gradation in importance—in a face-centred cubic lattice (Fig. 15, p. 75) for example the distance between atoms is greatest along the cube diagonal, while in a body-centred lattice this distance is least, although in both cases we are dealing with the three-fold axis! He realizes, too, that the arrangement is the same throughout the interior of the crystal. A return to abstract mathematics shows that relations can actually be co-ordinated which correspond to different modes, but the full reality of the crystal can not be grasped by this method. To render this possible it must be deduced from the corresponding modes and the combinations thereof. This is why in the following we wish to examine the crystal according to its layers of being, in order to recognize its whole essence.

As the first, innermost layer of the crystal the lattice must be described in the sense already laid down (Chapter IV). The lattice actually is the pure mode of the inorganic and as such it has no real being. The crystal, considered merely as lattice, does not contain anything material, and thus has no properties and has a purely mathematical significance. Its character is exhaustively described by spatial relationships. This is the definition of the *absolute crystal.* Since this is nothing but lattice, it possesses no boundaries (not even mathematical ones), but that implies that there is no shape.

It is clear that the absolute crystal as such can never appear. Reality can be attained only by interfering with the pure mode. Such interference can be caused by matter. The absolute crystal, interfered with by substance, appears as a *crystal skeleton* (*e.g.*, snow-crystals). Skeleton crystals possess no closed shape, but merely exhibit directions. For the idea of shape lies neither in the lattice nor in substance itself. The directions which do occur, however, are the main axes of the crystal. They appear isolated, without shape, and are nothing but a material precipitation of the interference of the crystal, which as such can not begin its existence. It is from this remarkable stage, where a crystal shape is altogether impossible, that crystallography must derive the justification for its axes, which it then uses for real crystals. This justification can be regarded only as a derived one, and its use is to a certain extent arbitrary. In actual fact axes lose their isolated character by virtue of the shape, that is to say, their reality is destroyed. They lead an existence only as crystallographic conventions, lacking true existence.

By means of substance alone the lattice can not be made finite, as is proved by the existence of skeleton crystals. For axes, like rays from a star, are directed towards infinity and the star remains the same, however small or large. Since the rays (axes), originating from one point, are never intersected again, they are infinite in every skeleton crystal. The lattice can only gain a finite and closed character by means of the shape. The shape is the ideal aspect of the crystal.

The definition of the *ideal crystal* is: the pure mode of the inorganic (the lattice) interrupted by the spiritual (the idea). The essence of the ideal crystal is that it has shape. By virtue of the idea all multiplicity becomes unity. In the ideal crystal nothing is isolated. Not only the axes, which have become visible in the skeleton crystal, but even the lattice planes and discrete points, which have their significance in the absolute crystal, are deprived of their existence by the idea. Atoms, even if they can be understood only from the mathematical point of view, play no part in the ideal crystal. The ideal crystal is a closed, completely homogeneous shape.

Actually, the crystal has this appearance only from the point of view of the idea, *i.e.*, of the shape, and there could be such an appearance only if it were a pure creation of idea, that is to say, if it were only shape. But the ideal crystal is a shape, which has incorporated the lattice in itself and must therefore contain the lattice with all its possibilities. If, therefore, it is regarded from the point of view of the lattice, the lattice planes and points (atoms) must appear in the same way as in the lattice itself. The only difference is that in the lattice they must have an unconditional significance, whilst in the ideal crystal their importance is conditional. They are and yet they are not; they possess a significance which has been curtailed. If the crystal be considered as shape, they disappear; if as lattice, they are the determining factor. In the lattice as such they have an actual, in the ideal crystal only a potential existence.

The ideal crystal is as little concrete as the absolute crystal (the pure lattice). Since it is nothing more than the annihilation of the lattice by the idea of shape, it has no substance in itself and can not therefore have any properties of its own. Even its shape is ideal, not concrete. It can thus never be measured and can not itself be determined mathematically without ambiguity. Every ideal crystal contains an infinite number of concrete shapes as possibilities. The complete series of these possibilities of its shapes is none other than what we earlier regarded as the "full form" of habits. The limits of these series are set by the lattice not by the idea itself. Even in a cubic lattice, however, the number of possible shapes always remains infinite.

(The cubo-octahedron combination alone furnishes an infinite number of habits.)

The *real crystal* originates by interruption of the ideal crystal by matter. (Interruption of the absolute crystal by matter results merely in a skeleton crystal as has already been explained in some detail). Its shape in contradistinction to the axes of a skeleton crystal, is always finite. Only the real crystal possesses material properties; hardness, weight, elasticity, firmness, compressibility, plasticity, cleavage, colour, etc. Since it has been entirely penetrated by matter it can show all properties of matter. It must have of course also an unambiguous, measurable shape. If it then is given possible faces, the justification thereof is followed from the ideal crystal, and in consequence is applicable only in a non-fundamental manner. For the real, concrete crystal possesses only one single shape, namely the faces which actually occur.

Neither the absolute, nor the ideal, but only the real crystal can enter into time. The real crystal, interrupted by time, gives the *historical*, *i.e.*, the growing and fading crystal. Even the real crystal is still without relation to time and its existence is merely spatial. It has neither commenced its existence nor can it ever fade, it can not grow or change. The historical crystal does originate, grow, change, and it can fade (by dissolving, burning, weathering, etc.) In short, it shows all the qualities of a mineral. Time is the pure mode of the organic; that is to say the historical crystal is interrupted by the organic as the ideal crystal is interrupted by the spiritual. The historical crystal, entirely concrete, contains all three modes. For the historical crystal contains the real, the real the ideal crystal, and the ideal the absolute. Therefore, the historical crystal represents the character of the crystal in its final concrete form, it is only at this stage that the full outer existence is reached. Every further interruption causes the crystal itself to break up and transfers it from the world of crystals to the realm of adhesion. The next step would be the interruption of the crystal by crystals, and this results in a structure which is no longer mathematical (the "texture" of mineralogy). Incidentally, since the changes in time and the fate of the natural crystal are usually outside the sphere of immediate investigation, and since these are really unpredictable (whilst in the case of plants and animals the normal course of their lives is known), the mineralogist when talking casually about a crystal does not usually refer to the historical, but to the real crystal. For the latter is the most readily apprehended of all.

But even the real crystal is not quite as clear and simple as it might appear at first sight. It can show all possible shortcomings and faults, irregularities and ruptures in its build, gaps, inclusions and admixtures. That is to say, it can reveal the mineral to an unlimited extent. Fine and beautifully-formed crystals are indeed rare, and some minerals, above all the precious metals, gold, silver and others, normally form poor, imperfect crystals. In order to understand the crystal even as a concrete individual, and in order to recognize its essence, it is necessary to determine clearly the *perfect crystal* and to separate its concept from the infinite mass of possible degrees of perfection.

Only the real, not the historical crystal, can be perfect. For what is perfect can undergo no change. But the historical crystal is subject to changes, and thus even as a conception is imperfect.

What then is the concept of the "perfect crystal"? —(*a*) That it is real; (*b*) That within the domain of the real it represents the ideal crystal as clearly as is possible within reality. From this the properties of the perfect crystal are determined.

Since the real crystal is nothing else than an intermingling of the ideal crystal with matter, but since this intermingling can not destroy, but can only materially fulfil the essence, the fundamental relationship of an ideal crystal must be fully obeyed in a real crystal—as long as it is to be perfect. That is to say, in the perfect, real crystal, as in the ideal crystal, the lattice must have been neutralized by the shape. The lattice planes and points have therefore not an actual, but only a potential existence in the perfect crystal.

The real crystal does not in fact show any planes in its interior except cleavage planes. But cleavage is not a property of the ideal crystal, and thus does not belong to the essence of the real crystal, but is formed by the lattice which is realized, *i.e.*, filled with matter. It is thus on the same level of being as the skeleton crystal. Since these two phenomena fall outside the essence of crystals, they play no part in the perfect crystal, in which everything is but realized essence. Cleavage is just as much a property of the imperfect crystal, as is the crystal skeleton evidence of the crystal which has not been materialized. Both are the result of a struggle between lattice and matter, in such manner that in the case of a skeleton, the lattice, in that of cleavage, matter, decides the issue. Both lie outside the perception of shape, and represent but axes (a skeleton) or planes (cleavage planes) respectively. As in the one case matter materializes mathematical axes, so in the other matter is merely cut by a mathematical plane. In both cases a disagreement in correspondence is evident. Abstract mathematics and tangible substantiality thrust directly at one another and in the former case there results no shape, which is essential to a crystal, and in the latter no unity, which with equal necessity appertains to matter. In a perfect crystal, therefore, it is self-evident that there can be no cleavage, for it is outside the general conception.

Not only in the ideal but also in the real crystal there are no material axes, as is shown by the crystal skeleton. The crystal axes have no real existence, but are useful mathematical devices which the crystal permits, but which it does not realize. Since they are not present in the real crystal, even less can they appear in the conception of the perfect crystal—they simply do not exist.

In a perfect crystal, but not in every real one, all planes, even the lattice planes, are annulled and can make no appearance. If in many crystals certain planes are revealed by striations, lamellar formations, cleavage directions and other indications, they are imperfections, which are brought about during formation or growth by outside influence. They belong in no way to the character of the crystal, but only demonstrate its imperfections. In the perfect, as well as in the ideal crystal, the planes are potentially and not actually present. They belong to the essence of a crystal—as distinguished from the axes and the cleavage direction with which the crystal as such is not concerned—but they can appear as such neither in the ideal nor perfect crystal, for they have become one with the shape, and have lost their identity in that unity. The perfect crystal is thus in reality entirely homogeneous, with a clear-cut shape outside and an undifferentiated unity within. Neither axes, nor cleavage, nor lattice-planes, occur in actuality. For the lattice has intruded into the ideality of the shape and thus can be realized not as such (as lattice) but merely in a unity with the shape, *i.e.*, as perfect crystal. The lattice is contained in the shape only as a potentiality, and thus if the shape be ignored and only the lattice sought, it can in fact be found by means of X-rays. What is found, however, is not the crystal, neither its character nor its reality, but simply the lattice with its mathematical significance. By means of diffraction patterns purely mathematical relations are determined directly; even the types of atoms must be found by evidence gained in a different manner, and must then be placed within the mathematical lattice. By means of a successful X-ray structure analysis, no more has been proved, strictly speaking, than that the mathematical lattice, which is reflected in the diffraction patterns, lies as a possibility in the crystal investigated. In fact it contains only this and no other possibility; the lattice is determined unequivocally. Nothing else at all concerning the crystal is revealed by the diffraction patterns. In fact they are not concerned with the crystal, for they indicate only the lattice as such. Now the lattice has in correspondence with its nature neither a limit nor a determined shape; the crystal investigated, however, has both. Whether the lattice is to be regarded merely as a possibility or also as a reality within the crystal, can not be decided by X-rays but only by our reason together with the aid of all mineralogical and crystallographic data concerning crystals. The X-rays are in no way capable of grasping the crystal as such—if they were thus capable they would at least indicate that the lattice is to be regarded as having only a potential existence, for the crystal is more than a sum of facts, it is in its essence a unity. But in such a unit, the lattice and atoms can be included merely as possibilities, not as realities—otherwise there would be no unity, but a summation of atoms, and we should be investigating merely an atomic structure, no longer a crystal. The crystal, however, which by virtue of the idea has become a completed shape, neutralizes the atoms, together with the lattice, within itself.

The perfect crystal, in the same sense as the ideal crystal, is a unity of lattice and shape, or the neutralization of the mathematically arranged points (atoms) by the pure unity of the idea. In its interior the substance lies suspended in homogeneity, with the possibility of discrete lattice points as well as the perfect unity in shape.

If the real crystal is to be perfect, the ideal one within it must be fully penetrated by matter. The perfect crystal itself is nothing else than the complete penetration of its essence with matter. Admittedly it is not possible that in the unification of matter the ideal crystal can still be identical with itself. For all that which is filled with matter, is concrete in this fulfilment, and can occur but once and has no other possibility of existence but the one which has been realized. The ideal crystal includes in its ideality an infinite number of possibilities of fulfilment, *i.e.*, an infinite number of special shapes. In the real crystal, on the other hand, only one of these shapes may be realized: the perfect crystal is thus necessarily a specialization and solitary representation of its character; in this respect it will always be inferior to the ideal crystal. But in this solitary representation which appears in this one shape, the perfect crystal must be a complete interpenetration of its ideal unity with mineralogical substance. In this one shape all relationships of the ideal crystal—with the exception of the other possible shapes—must exist unimpaired and must exist in unity with the substance. The crystal axes, which appear embodied in the skeleton, do not belong to these relations, since they do not lie within the essence of crystals and in fact never appear in a real crystal; the cleavage plane which in most crystals appears more or less distinctly, is concerned—as we have seen—with the substance alone and does not enter the crystal. The lattice planes on the other hand must have the same significance in the real as in the ideal crystal and just find fulfilment by substance. Matter in a perfect crystal must, therefore, reach the same unity with the lattice as the shape itself. In a perfect crystal the planes will not appear directly (for the interior appears entirely homogeneous), but when one is concerned with the lattice alone they are prominent. The lattice responds to pure mathematical analysis. Mathematical distinction is made by X-rays of known wavelengths.

The perfect crystal thus gives the same picture in reality as the ideal crystal in ideality. Given that one is searching for the lattice as such, that is to say without unity of the shape, then it must appear even in a real crystal, in spite of the penetration of matter, and in a perfect crystal in the full purity of its mathematical relations. Matter thus has no will of its own belonging to its essence, but it yields itself freely in mere fulfilment of those relations which exist in the ideal crystal. Only when matter enters the crystal entirely without influence can the real crystal be perfect, for otherwise it will lose its perfection on realization.

We come, therefore, to the second point regarding the relation between matter and ideality, which must occur in a perfect crystal. Matter itself has necessarily no determining influence, but the matter taken up by the crystal is always in some way orientated, for what enters the crystal is not absolute, but mineralogical substance, which possesses definite properties. Rock-salt even when in solution behaves differently from sylvine, gypsum or calcite, fused gold, copper or iron. As far as the substance remains itself on entering into the crystal, *i.e.*, as long as it remains sylvine, or calcite, gold, or copper, it can never form a perfect crystal. For the properties which the substance retains instead of yielding up can not enter the crystal, which is a pure shape, but are attached to it as mineral properties. This means that the crystal is not merely crystal, but is also mineral. But a crystal which is not a crystal through and through, can not be perfect. *In a perfect crystal, therefore, the properties of the mineral must themselves become crystallized, i.e.*, they must be a fulfilment of its essence. This essence, however, they fulfil by representing the relations of the ideal crystal, each in their manner but perfectly. From being significant of the substance they simply become significant for the crystal.

In a perfect crystal this is actually the case, for all properties of matter such as hardness, elasticity, compressibility, fracture, solubility, and the electrical, optical and thermal properties in such a crystal are *orientated, i.e.*, they are in correspondence with symmetry. They are thus determined for the crystal and no longer for matter itself.

We will disregard in this connection the electrical, optical and thermal properties, in order to simplify the argument. As concerns mechanical strength and elasticity the following statement may suffice: during an investigation on rock-salt it was found that a little rod cut perpendicular through a cube face could be broken by a weight of 1 kilogram, a similar rod cut perpendicular through an octahedral face broke only under twice that weight, whilst one cut perpendicular through a rhombic dodecohedral face was broken by 2.6 kilograms. Plates of "Bergkristall" which were tested for musical pitch differed by as much as a fifth according to the direction in which they were taken from the crystal.

The case of hardness of crystals is particularly clear. Different faces on the same crystal show different degrees of hardness, and indeed sometimes hardness may vary on the same face with the direction of scratching. The exact laws may be omitted here. The connection of hardness with cleavage is, however, remarkable. Differences in hardness are exhibited only in those crystals which possess cleavage. In fact there is an exact orientation to the cleavage plane! (Faces parallel to the cleavage planes have the least, those perpendicular the greatest hardness). The so-called "percussion figures" can be comprehended even more clearly. They are produced by driving the point of a steel pin into the crystal face by a light blow. The resulting fissures meet at the point of intrusion and form star-like figures, which always correspond to the symmetry of the planes. On the cube face of rock-salt two perpendicular fissures occur, parallel to the directions of the diagonals of the face, while on the octahedral face a star appears whose rays are perpendicular to the edges. Monoclinic plates of mica give as percussion figure three fissures, one of which, the longest, lies along the direction of the plane of symmetry, whilst another pair of equal fissures cuts the former symmetrically (Fig. 47). In this way percussion figures always give an exact image of the symmetry relations of the face on which they appear.

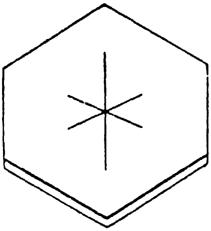

Fig. 47. Percussion figure of mica.

Percussion figures are intimately related to cleavage; in both cases we are dealing with the division of matter (the mineral) along planes. Both appear to depend directly on the lattice and not on the shape of the crystal. Cleavage occurs, usually in varying degree, in one or two and rarely in three planes, whilst the percussion figure shows the full symmetry of the face. Both, however, represent the relations of the lattice as such, and not the crystal in its unity. The cleavage plane passes unimpaired through the whole crystal shape; the faces of the habit, which intersect and at the same time bound one another, have no influence on it, but are cut arbitrarily by it, sometimes, in fact, it coincides with no crystal face and thus ignores the whole system of faces. The fissures of Fig. 47 actually occur parallel each to one pair of faces, but nevertheless a cut in their direction would destroy the shape with equal arbitrariness. Only the main fissure divides the crystal into two symmetrical halves, the other two contradict the habit and even if the percussion figure is in a central position, do not run towards the corners of the face. Planes, if they appear as crystal faces, and if they have been incorporated in the unity of the shape, are divorced from this unity in the percussion figures. The faces of the habit, however, belong to the crystal, the fissures of the percussion figure, on the other hand, only to the lattice.

Percussion figures, as well as cleavage, fall, therefore, outside the essence of crystals and it is thus impossible for them to appear in the perfect crystal. How is it then that a perfect crystal is possible at all in the case of minerals which show cleavage and percussion figure? Is it always, so to speak, composed of a cleavage—or percussion—crystal, *i.e.*, of the planes of cleavage or percussion figures? And yet, they are planes which belong to the lattice, and do not appear to have been taken into the unity of shape! It must not be overlooked that the crystal has actually to be affected mechanically, cleaved, or separated by a point, in order that these planes may appear. The cleavage planes and fissures occur only in a crystal already cleaved or ruptured, and this wounded crystal is of course no longer perfect. Before cleavage takes place there is in the crystal—providing it is of perfect formation—neither a cleavage plane, nor a fissure, and the planes of the lattice have been wholly incorporated in the shape and can not be recognized as such in any way. However, the lattice, since it is potentially contained in the crystal, must be in such a position that it can be revealed and must be able to manifest itself by some means. Such means are, apart from X-rays, provided only by the mechanical effect of a blow or pressure. The lattice, which in the unity of the undamaged crystal was entirely neutralized and had vanished within its interior, is divorced from its unity by the mechanical constraint, and is revealed as purely mathematical orientation of the cleavage plane or percussion fissure. Cleavage and percussion figure are thus no contradiction to the perfect crystal, but are in fact a proof that the lattice is really present in it as a possibility, although it does not appear directly in any way and although in the unity it cannot be detected. The evidence of cleavage and percussion figures involves at the same time the destruction of the unity and thereby the annihilation of the perfect crystal itself. With isolation of the lattice, the crystal has necessarily gone astray, for its essence consists in the unity of lattice and shape. Under the discriminating influence of X-rays every mineral reveals its lattice; but even here the crystal must first lose not only its ideality, but usually also its full reality, in that it is rubbed down, cut into little plates or even ground into a powder (as in the Debye-Scherrer method) before its structure can be determined. The mechanical influences do not always achieve this aim; not every mineral possesses cleavage, nor does every mineral give clear percussion figures. The crystal, therefore, does not set free the lattice, but can only be destroyed as a unity. Fundamentally, however, all minerals can form perfect crystals.

Finally, the same is true of hardness. The latter, too, can only be determined by affecting the crystal mechanically and by breaking the coherence of the particles. The ability of the particles to separate, which receives its clearest expression in the cleavage plane, is tested now in a different way, by scratching, and it is therefore not as strange as it might appear at first sight, that hardness shows such a definite connection with the cleavage. The ability to be scratched is merely a different aspect of cleavage. It is granted that they can not merely coincide, since the means and the way in which the particles are pulled apart differ. The crystal build usually exhibits a greater differentiation of degrees of hardness than in the case of cleavage directions. But nevertheless the hardness, too, can be a property of matter only, and its orientation merely an image of the lattice, not of the crystal as a unity. Thus, even by scratching, the lattice is removed from its unity with the shape, and is isolated. The scratched crystal is a wounded crystal, deprived of its internal unity, and therefore no longer a perfect crystal. The crystal as such can show no differences in hardness, in fact it can not possess any hardness at all, for hardness is a property of matter. But this is simply a further demonstration of the fact that all properties of matter do enter into the crystal, and are contained in it no longer as properties of matter, but obey the crystal law, *i.e.*, are orientated in correspondence with the lattice. They exist, together with the lattice, in complete unity, neutralized by the shape. If the lattice is torn from the unity by outside influence, as by scratching in this case, then the hardness and every substantial property emerge in an orientated manner. In a perfect crystal they can not really be orientated, but only neutralized, *i.e.*, they can only be present potentially. In spite of this they must be imagined as potentially present, and orientated within it by the ordering effect of the lattice, that is to say they obey the crystal, and no longer matter. In fact they are impossible to determine and there is no meaning in the question: what is the hardness of substance as such? In the substance it could at most only be imagined as non-orientated, *i.e.*, completely without directions. For the degree of hardness is determined entirely by the crystal. From this it necessarily follows that even for minerals that show no differences in hardness in the crystal this one degree of hardness does not belong to the substance as such, but is determined equally by the crystal and is incorporated entirely in the unity of shape. The uniformity of hardness in such crystals is but an image of the uniformity of the crystal in its completed form. It remains remarkable and without possible explanation that some minerals on scratching allow the lattice to leave the unity of the crystal, and thus allow it to show orientated hardness, whilst others retain their unity even after the infliction of injury, and thus show no difference in hardness. This is, however, no more remarkable than the fact that certain minerals show cleavage and percussion figures whereas others do not. In all three cases the deeper reasons are unknown to us.

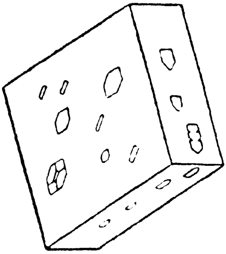

Fig. 48. Etch-figures on a barytes crystal. (From Tschermak).

A particularly fascinating reflection on the crystal interior is the so-called etch-figures, which are produced by exposing the crystal to the weak influence of an etching fluid. They consist of small single cavities which on careful handling show distinct outlines and which are bounded by plane faces. The shape of the figures reflects—as in the case of percussion figures—the symmetry of the etched face. In this way four- or six-faced disymmetric figures are formed on the pinacoid faces of the rhombic barytes crystal (Fig. 48), and on the rhombohedral face of calcite (Fig. 49) there appear formations which are "faces of three different scalenohedra and of one rhombohedron together with the face parallel to the fundamental rhombohedron"* (etch-figure *b*).

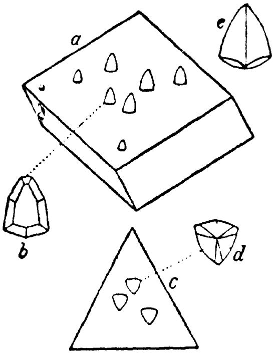

Fig. 49. Etch-figures on a cleavage fragment of calcite. (From Tschermak).

As regards the explanation of these figures it is at once clear that they owe their origin to the imperfection of the etched crystal. If the finer structure were entirely the same on the whole etched plane, then under the uniform influence of the solvent, no figures could have been formed, but the whole face would be dissolved away layer by layer as a continuum. The cavities thus indicate regions of greater solubility of the substance. But since the solubility, as every other property of matter in the crystal, must be determined by the lattice, the etch-figures are a demonstration of the irregularity of the crystal build on the face concerned, in fact are an indication that the absolutely perfect crystal—at least of some size—can not be assumed to exist in reality. But even in the approximation the conception must be a completely clear and unambiguous one.

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*Tschermak, "Lehrbuch der Mineralogie", p. 145.

There is no other means by which the structure of the interior of the crystal is so intimately and convincingly illustrated as by the etch-figures. The shape of the figures, however, indicates to us the several ways of interpreting the crystal as reality, as pre-assumed in the concepts of the possible but non-existent faces. What else but possible crystal faces can these four- and six-faced etch-figures mean, which occur at the same time on the same face under the influence of exactly the same solvent? The habit which is actually present is only one of the possibilities which are reflected in these little figures. How nearly equivalent must be these different potential habits in the crystal, how labile the equilibrium, if such intangible coincidences, as alone can come into consideration here, decide for the one or the other possibility. The "faces of three different scalenohedra and of one rhombohedron together with the face parallel to the fundamental rhombohedron"—is it not the entire ideality of the crystal which shows up in these delicate figures? One single shape is present and the others (four) are shown to us as being equally placed and actually of equal importance in the interior. The essence of the crystal can not exhaust itself in one shape, for it contains many potentialities within it, and only the totality of these possibilities shows its essence, the ideal crystal. The real crystal in its solitary actuality has but a dimmed splendour in comparison with the ideal crystal which is hidden within it. This ideality is, however, most characteristic of the crystal and imparts to it in spite of the apparent exactitude of its shape, a wonderful freedom, delicacy, and multiplicity, which come into appearance, particularly in the light of the crystal sphere (p. 185 ff.).

As the positive confirmation of these negative images, the etch projections (Plates IV and V) appear with the etch-figures. Cubic galena, for instance, which crystallizes usually in cubes, seldom in octahedra, and which cleaves parallel to the cube faces with extraordinary perfection, shows eight-edged pyramids on its cubic faces when acted upon by hydrochloric acid for some time. These faces never occur in the habit, nor does the cleavage direction betray them, and yet they must lie in the crystal as possibility, and they are part of its essence just as much as are the cube or octahedron.

Who in the face of this could venture to regard the crystal as coarse matter and its atoms as real structural units, as physical atoms? If they were so, from where would they derive their multiplicity? The given number and equally given order of the real atoms could only constitute an equally given final form, an edifice of atoms, which in its shallow reality would exclude the mysterious vitality and multiplicity, even infinite variety, of the crystal. Almost every type of effect produces a new form, new relationships, and new possibilities. Hardness, cleavage, firmness, elasticity, etch-figures, and etch-projections, and finally all the phenomena of light and colour (interference phenomena*) in a crystal merely demonstrate different aspects of an incredible and probably inexhaustible essence, and new methods of investigation, which are yet to be discovered, will be able only to elucidate new aspects, but none will be able to express the whole essence. Accordingly is it not to be expected that even the crystal lattices, which can be calculated by means of X-rays, are but a new, though perhaps very important aspect, in the truest sense only a reflection of its inner but never fully manifested character? Will all possibilities in the course of time be deduced from the lattice? One would have to calculate the idea and be able to describe it geometrically if one were to succeed in exhausting the crystal mathematically. For the idea, as shape, is just as much present as the lattice, and idea fulfils it with infinite vitality. But since the idea of the crystal has no purpose in itself, and since the perfect shape appears entirely for its own sake, whilst the organic world includes a purpose in all its creations, the crystal is probably the most delicate and at the same time most pure formation of the universe.

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*Unfortunately a description of interference figures, which appear in the "conoscope"—they are most charming pictures, in which the crystal appears coupled with the light—must be dispensed with owing to the difficulty of the subject matter.

CHAPTER NINE

CRYSTAL AND COLOUR

COLOURED crystals are more abundant than colourless ones. Yet the colour is not a property of the crystal but of matter. If it were due to the crystal, the same mathematical relations would be connected with the same colour, which evidently is not the case. Quartz, for instance, which crystallizes in the trigonal trapezohedral class, can occur not only in very different colours; grey as in smoked quartz, black as in morion, yellow as in citrin, and violet as in amethyst, but as Bergkristall it may appear completely colourless. Nevertheless all these types, must be based on the same lattice.

The questions now arise: (1) in what way can colour enter the crystal, *i.e.*, appear orientated?—and (2) is it reconcilable with the perfection of the crystal or not?

A fleeting glance at coloured crystals shows that the colour is not able to gain the same strict relation to the crystal structure as can perhaps the mechanical properties of hardness and elasticity, and even cleavage and percussion figures. The differently-coloured layers, or the differing colour of the cube faces, which can be observed in fluorite, are not real reflections of the internal structure, in which all points and all layers must be entirely equivalent. The differently-coloured layers reflect nothing more than the course of growth, that is to say, a happening of time, which does not belong to the strict concept of the crystal. As a real image of the crystal build the orientation of colour may appear on augite (Fig. 50). In the section of the monoclinic crystal the outer layers, corresponding to the side faces {100}—left and right on the sketch—show a violet, whilst at the ends parallel layers—at the top and bottom—show a yellow, colouration. The phenomenon is so extraordinary that Becke's theory of growth-pyramids gains a certain justification, or at least some value, as an explanation. The growth-pyramids or growth-cones are obtained by an imaginary cut through every edge of the crystal towards the centre of the crystal, so that every crystal face appears as the base of a pyramid, whose summit lies at the centre of the crystal. In reality, however, this conception of the crystal contradicts its character just as much as does the apparent orientation of the colour. In the perfect

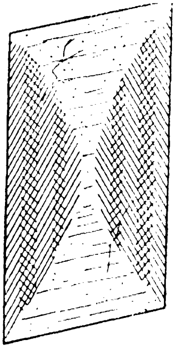

Fig. 50. Section of an augite crystal. (From Tschermak).

crystal neither axes nor centre have any particular importance, and certainly not the intersection planes, which are not even anchored in the lattice. These pyramid sections correspond neither to present nor possible crystal faces, but are merely useful mathematical conceptions, which in the crystal as such are in no way realized. They, too, are mere indications of events during growth. These intersection planes represent all the edges which have formed during growth by the layers which are added on to the crystal one by one. The perfect crystal, however, can not show a trace of its origin, and is not built up according to layers of growth, but according to the entirely abstract planes of the lattice, every one of which is fundamentally and infinitely valid throughout the crystal. The varying colour in the augite crystal on the other hand, which forms a point of intersection at the centre of the crystal, is in reality orientated not spatially but once more only in time, and in the perfect crystal it can thus not be suppressed. Colour would be truly orientated in the sense of the crystal shape only, and would thus be a reflection of the lattice, if the crystal were to show different colours in sections according to present and possible crystal faces, but it shows always only one colour in a given direction identical along the whole section. It is just this orientation which does not occur in crystals. In all other cases, however, colour remains a property of the substance and is thereby excluded from the crystal itself. Whether colour is at all compatible with the perfection of the crystal can follow only from an investigation of its character.

Mineralogists are in the habit of distinguishing the "self-colour" from "foreign colouring matter". In the latter case we have those minerals which in their pure state are colourless (quartz, beryl and calcite, for instance). The colouration which they otherwise show, is not due to themselves but to foreign colouring matter, which is more or less uniformly, sometimes with a sub-microscopic fineness, distributed throughout the crystal. Smoked quartz and morion can be made colourless by strong heating, amethyst at 250°C. changes its derived violet colour into an equally derived yellow colouration.

That the foreign colour can not enter into the crystal lattice is obvious. If the pigment were crystallized, it would have its own lattice, which would have to contradict that of the crystal, whose guest it is, since they would have originated from two different substances. If it is not crystallized—which in all probability is invariably the case—but is distributed throughout the crystal more or less with colloidal dispersion it would from the very beginning interrupt the crystal structure with non-mathematically arranged matter. In either case the coloured substance would have to remain outside the crystal structure.

This means that for the perfect crystal its self-colour alone can come into consideration. First the conception itself must be explained. The mineralogist is naturally thinking in the case of the colour of a sulphur crystal only of the yellow of sulphur, or in the case of gold or golden-yellow, for those are the colours in which the two minerals usually occur. In transmitted light thin gold leaves show a decided green colouration and finely-divided gold, which can be obtained by precipitation with oxalic acid, also appears green, or if still more finely divided, blue; the finest colloidal gold, however, has a red glow like ruby. This means that besides the colour signified by the name of gold, there are also green, blue, and ruby-red, as well as all intermediate shades. The same applies also to other metals. Silver for instance, according to the fineness of division can appear yellow, orange, red, violet, blue or green. In colloid chemistry gold, silver and platinum are in fact described as *pantochrome* (of all colours). This variety of colours is by no means restricted to metals. If sulphur is precipitated colloidally from a salt by an acid, the particles gradually attain a coarse state of division which is recognizable as thick milky turbidity. The translucent colour of the solution, however, passes during the increase in size of the nuclei through all transitions of orange, red, violet and blue. The final stage is an opaque grey.

In all these cases the substance remains chemically unaltered. The gold assumed all the colours as gold, the silver as silver, and the sulphur as sulphur. What colours do gold, silver, and sulphur really possess? All—and that means none! For if the colours could change freely in the gold, whilst it remains an element, this could be no property of the gold itself. Not matter as such, but the size and shape, or perhaps the motion of the particles, must be the cause and carrier of the colour.

All these colours are not only formed in liquid solutions, *i.e.*, in "suspensions", but can be obtained also in solid bodies. Ruby glass owes its colouration to that same colloidal gold, which in suspension shows that deep colour. In the glass as in the liquid the colour changes with the size of the gold particles. Sulphur is in fact employed in the preparation of dyes. Ultramarine owes its colour to sulphur, which is mixed with other substances (silicates, borates, etc.). According to the thermal treatment the same mixture can produce colourless, grey yellow, red, blue or green ultramarine. Here, too, the colour changes according to the size of the sulphur particles, which can have all colloidal dimensions down to that of the single molecule. It is impossible to ascribe a definite colour once and for all to sulphur, gold, silver, etc. The same, however, must apply fundamentally to every mineral, although it may not always appear so clearly; no substance as such has a definite colour.

According to the wave theory of light this seems quite evident, for on this theory colour is nothing but light of a certain wave-length, between about 800 μμ (the furthest visible extent of the red) and about 400 μμ (the visible limit of the violet).* Colour can be produced by analysis of sunlight by means of a glass prism, or by diffraction on passing through a slit, or finally on bodies which absorb certain wave-lengths, whilst the rest are reflected as colour. If in this connection we neglect the prism spectrum, only fine structure of a body can be regarded as responsible for the colour. In the case of the diffraction spectrum this is immediately clear. The transmitted light is diffracted towards the side in coloured rays by the diffraction lattice of a system of very thin slits, scratched on a little silver leaf. The colours thereby produced are obtained by superposition (interference) of rays *having* a difference in phase. But prism- and diffraction-spectra are coloured rays produced by bodies which are themselves colourless or, at least, which do not possess all the rainbow colours which under certain circumstances originate from them. Much more important than these two types of coloured rays, which play their part mainly in optics and in the appearance of a rainbow, are the dyes of every-day life. All bodies and substances which show always the same colour in daylight, such as minerals and plants, garments, paper, paints and all coloured pigments, are either colouring matter themselves or owe their colour to such substances. In dyes, however, it is as we have seen nothing but the colloidal division of some substance which gives them colour. Coloured earths, such as burnt sienna, umber and red and yellow ochre, are natural gels, *i.e.*, they have from the very beginning a colloidal structure. In sulphur dyes, which are produced by fusing sulphur with various organic compounds, the colloidally distributed sulphur is probably the carrier of the colour. Now if the state of division, *i.e.*, the size, shape, and distance between the particles, determines the colour, then the chemical substance as such can not be reflected in it. but only the microstructure. We shall not discuss here how the process is to be imagined in detail, and why certain wavelengths are preferentially absorbed by bodies. Colloid chemistry makes it indisputable that the sub-microscopic structure alone decides the colour.

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*1 μμ = 10 A = 1 millionth of a millimetre.

The question whether or not colour can enter into the perfect crystal almost answers itself. As experiments in colloid chemistry show, the colour reaches its greatest expression in the realm of colloidal division.* It decreases with increasing size of the nuclei as well as on approaching molecular solutions. In the former case the end is a non-transparent coagulation product (as in the colloidally precipitated sulphur), in the latter it is a transparent colourless solution. Colour thus appears in truth to be linked with the colloidal state of matter.

The atom, or molecule, can itself no more show colour than it can show a state of aggregation. In the highly dispersed colloid, colour is in all probability produced rather between than on the particles, and is determined chiefly by the intervening distances. Molecular solutions, as the observations of colloid chemistry at least strongly suggest, are colourless. It can hardly be imagined otherwise, since the atoms make up only a four-thousandth part of the wavelength of light and thus are probably unable to produce interference. Otherwise it could scarcely be understood why colours are not produced with equal facility on shining sunlight through a crystal. Atoms and molecules thus lie below the limits of the colour region.

Now since colour is linked to the colloidal state of matter, and since colloid and crystal are strictly divided from one another, and neither can be transformed into the other, (cf. p. 50 ff.), it already lies within the characteristics of colour that they can not enter into the crystal themselves. It can creep in as foreign matter, but as an interruption it remains, just like foreign colouring matter, outside the crystal structure. But even a characteristic self-colour can not occur within a crystal; otherwise the substance which forms the crystal would be colloidal at those points, *i.e.*, non-crystalline, and, therefore, a mere stranger, an inclusion in the crystal itself. Every crystal, however, which contains non-crystalline matter, be it the same or a foreign substance, can for that very reason no longer be perfect. The conclusion necessarily follows that the *perfect crystal* must be colourless. Still more must it be *transparent*. The tendency towards transparency is quite unmistakable in crystals. Actually by no means all crystals are transparent; those of some minerals, in particular those of metals, never are. But if ever a crystalline substance is transparent this is due to the crystal. If a crystal of any substance whatsoever is opaque, it can not be perfect. For the transparency is necessarily linked with the completely ordered arrangement of atoms.

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*Instead of limiting the colloidal region arbitrarily by numbers (100—1 $\mu\mu$ particle diameter), it might be advisable to define it in fact as that division which causes colours to be produced. One could not in that case name any exact numbers, but the determination would have an enhanced significance.

Here also colloid chemistry is rich in proofs. The most highly-dispersed silver sols are a transparent yellow or greenish-yellow. The higher the dispersion and the more transparent the sol, the weaker the colouration. It can be concluded with safety that the final stage in the decrease in size of the nuclei, *i.e.*, the molecular solution, is entirely colourless and perfectly transparent. Phenol and water mix at normal temperatures only partially and on shaking give an emulsion of white colour, *i.e.*, non-transparent. If the mixture is heated above 70°C. it becomes perfectly colourless and at the same time transparent; the two liquids form with one another a molecularly dispersed solution. On cooling a progressive separation occurs, together with a bluish-yellow opalescence, until a white non-transparent emulsion is formed once more. This means that even colloids must clear to a complete transparency, as soon as molecular dispersion occurs. Only intermediate structures trap the rays, and prevent the passage of light, so that colour and turbidity appear. If the *molecules*, at the final stages of the progressively dispersing colloid, no longer have an effect on the light, then the mathematically ordered atoms of a crystal must show the quality of transparency. If a crystal is coloured or opaque, its inner arrangement must be disturbed, or interrupted by foreign structures, *i.e.*, it can not be perfect.

The perfect crystal must therefore be transparent, which in reality means invisible. For if the light on passing through the crystal is in no wise changed, the result must resemble the passage of light through empty space. Light itself, however, is known to be invisible, as long as it does not strike material particles and as long as it is not reflected. We can see only the objects on which it falls, and by which it is reflected, or the shining bodies from which it originates (*e.g.*, the sun). In "optically empty" space, *i.e.*, in absence of even the finest dust particles, which have an effect on the light, we could stand in a stream of bright light and yet, as long as we did not look into the source of light, we would be unable to perceive the slightest indication of the light. In fact in water which has been freed from all foreign matter—*i.e.*, optically empty water—the light of an arc lamp on passing through it, is quite indiscernible to our eyes. The light, which is described as "visible" light in contradistinction to X-rays, is in fact invisible. The perfect crystal is equally invisible. In comparison with other bodies it is in fact perceptible to the eye, because the light during passage is diverted (refracted), so that the objects seen through the crystal appear displaced relative to the rest of the surroundings. This would be the only indication by which we could recognize the presence of the crystal. But in one way it could still reveal itself. If we place perfectly clear transparent glass on an object it appears to gain in brightness, although the light has been weakened by the glass, since at least part of it is lost by reflection. In pictures behind glass, particularly if a piece of the glass plate is missing so that covered and exposed parts are next to each other, one can recognize without difficulty the enhancing effect of the glass. It appears as though it gave some sort of glow to the colours. A similar or perhaps stronger glow should radiate from a perfect crystal. For the purest glass can not compare in perfection with the crystal. The perfect crystal is a source of clear, transparent glow—it shines from within. Since, as a perfect crystal, it has also a perfect shape and since it is bounded by flat, glistening faces which reflect the light not only to the outside, but which send it frequently backwards and forwards, pass it to and fro and cause it to sparkle, a lively play of the light results, as one can actually see in a marked degree in diamond. The "fire", however, which one praises in it, is that enhanced glow, that very shine which comes from it like a mysterious force, and which appears to be imparted to other objects.

CHAPTER TEN

THE CRYSTAL GLOBE

HAD the first crystal globe* been made by a mineralogist with the purpose of allowing the crystal to reveal its nature in the globe, this would undoubtedly have been an ingenious achievement. For every thing is best recognized only by another thing foreign to it, or best of all by its opposite. To the crystal, which is composed only of straight lines and plane faces, but not of curves, the sphere, as the most perfect curve in three-dimensional space, is entirely foreign. In reality, however, single crystals were produced at first in wire form and last in spherical shape in the laboratories of technical companies, not for the sake of that recognition of crystal character, but for the study of certain properties of the material and its uses The charm of these single crystal globes is of course in no way diminished by this, and the wonder which breaks forth from their interior is apparent to all those who can grasp and appreciate it. For the secret of the crystal is nowhere seen so directly as in the mirror of these etched globes.

The author had at his disposal one of the most interesting single crystal spheres which had been obtained from the fused state more than a decade ago*. The globe, which was obtained from a single copper crystal is about 5 cm. in diameter, has been etched and has been covered for protection against oxidation by cellulose varnish. Since all points on the surface and within a crystal are absolutely equivalent, nothing could be noticed on the sphere itself which would reveal whether or not the contained crystal had a regular shape. The globe reveals nothing beyond the fine structure which has been freed by etching.

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*See "Metall-Einkristalle" by Karl Wilhelm Hausser and Paul Scholz. (Wissenschaftliche Veröffentlichungen of the Siemens Co., Vol. V., No. 3. Berlin, 1927, Julius Springer.)

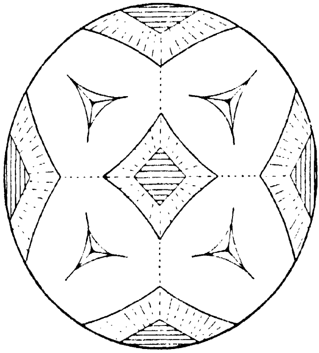

Fig. 51. Scheme of a single crystal globe of copper.

The shape of the sphere, like the passage of X-rays, addresses a kind of question to the crystal. And the crystal gives a clear, though at first sight surprising reply. For on the delicate gloss, which plays over the sphere, not all possible, but only some preferred faces are evident.

Our sphere, schematically shown in Fig. 51, shows six clearly defined glowing black spherical squares, whose sides subtend about 20° of arc at the centre of the sphere. (In the sketch, on the surface of the sphere, which has been projected into a plane, the centre square alone appears completely and of the correct dimensions: the four neighbouring ones are halved, and correspondingly distorted). Pairs of two squares lie diametrically opposite one another. The six crystal planes which are revealed thereby lie therefore parallel in pairs, *i.e.*, in such a way that the three corresponding sphere diameters are mutually perpendicular. This means that the crystal is cubic and the squares represent its cube faces. The fact that they are not standing on edge, but, as in the cube-octahedron, on their points, only proves that they are intersected by some other type of face, (perhaps the octahedron).

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*The crystal sphere is the property of the poetess Erika Spann-Rheinsch, who had the kindness to permit the use of this fragile specimen for the investigation and the photographs.

The octahedron itself is not reflected on our globe, but the centres of the faces are marked by greenish points, which appear to lie inside the sphere, and from each of which emerge three weak lines in equiangular spacing towards certain directions. (In the sketch there are visible naturally only four of the eight triangles). If one imagined a cube to be placed inside the globe, its eight corners would touch the surface of the sphere exactly at the octahedral points and the lines would correspond to the directions of the cube edges. On the basis of these two pieces of evidence (cube faces and octahedral points), not only the symmetry but also the orientation of the crystal which underlies the sphere is perfectly clear.

Of the other faces of the cubic forms, only the icositetrahedron can be seen directly on our crystal globe (shaded in the diagram). As a square frame of the black cube faces they stand out by their golden gloss, and may be distinguished from the reddish glitter of the octahedral faces.

The icositetrahedral faces also have quite a definite width (about 21°), so that the side of the outside square is about 41°. Of course, these distances can not be determined accurately by means of a protractor since the bounding lines, particularly those of the octahedral faces, do not give a sharp contrast, and since they move markedly with the positions of the observer, and of the source of light, and also since they do not run in straight lines, but (according to the inclination) more or less in curves.

It is curious that one and the same crystal reflects, according to the etching agent used, different crystal faces. "For instance the pure rhombic dodecahedral faces are obtained, if the sphere, after it has been freed of the surface damaged by the treatment with a polishing macerator, is then dipped alternately into solutions of ammonia and hydrogen peroxide. The pure cube faces are obtained most simply in nitric acid containing silver. Even combinations of several forms can be prepared at will".* In this way the preparation of a globe has been achieved, on which all the seven chief holohedral forms can be detected.

The reflection of the crystal faces is therefore not brought about by the shape of the sphere as such, but principally by the exposed microscopically small etch-crystals. Plate III shows the centre of a dark square of our crystal sphere enlarged fifteen times,

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*Hausser and Scholz, "Metall-Einkristalle", pp. 159-160.

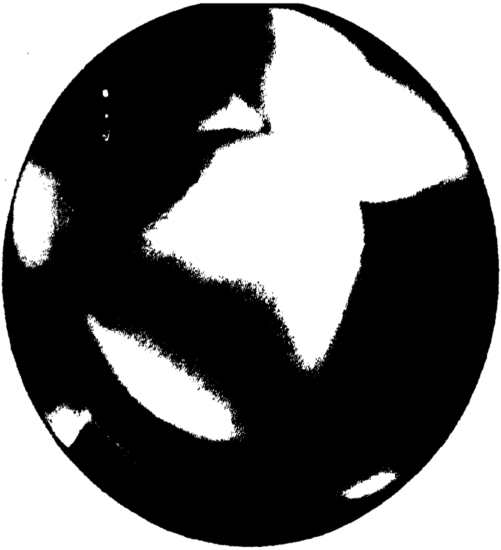

Plate II. Crystal globe of copper. (Enlarged).

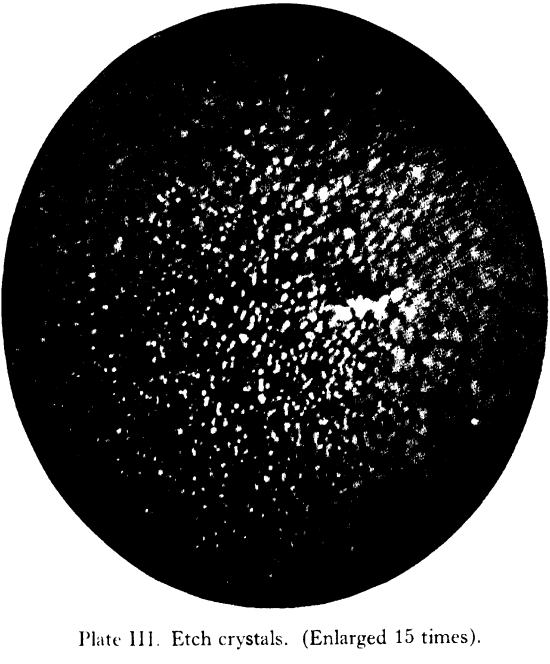

Plate III. Etch crystals. (Enlarged 15 times).

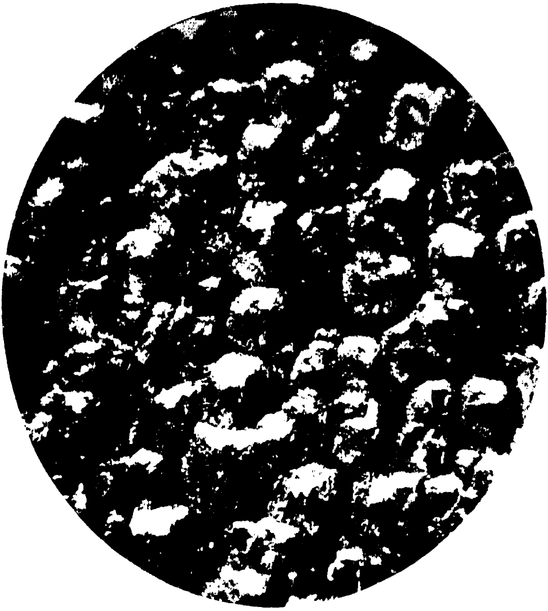

Plate IV. Etch crystals from the centre of the cube face.

(Enlarged 94 times).

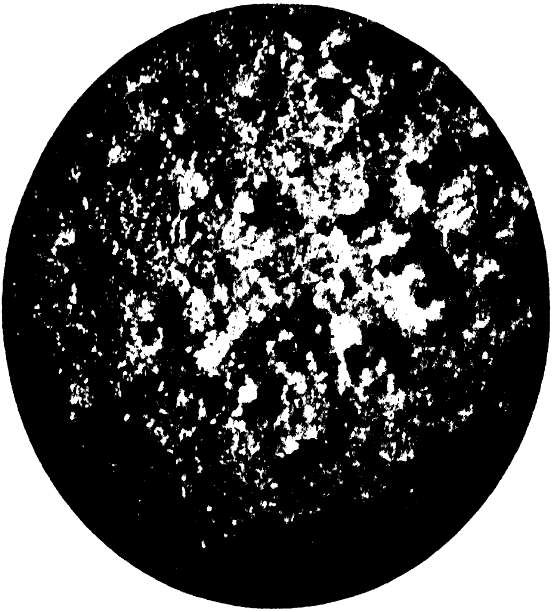

Plate V. Etch crystals near the edge of the cube face.

(Enlarged 94 times).

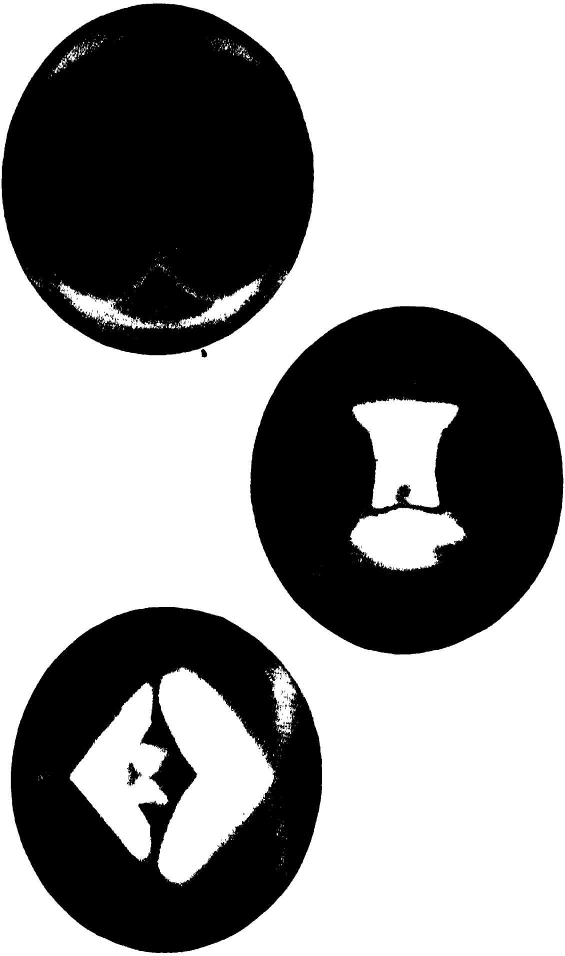

Plate VI. Three views of the crystal globe.

(Somewhat reduced in size).

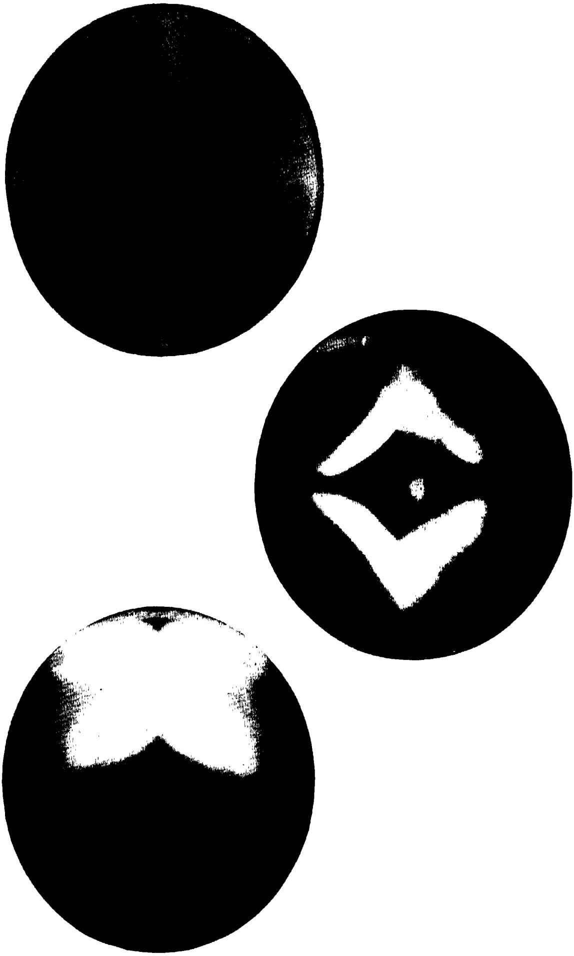

Plate VII. Three more views of the crystal globe.

Plate IV a tiny field, smaller than 0.8 mm.^{2}, enlarged ninety-four times. The cubes, which look rather like cobbles, in reality have edges of average length of 0.06 mm.; they are lying in a horizontal position on the surface of the globe and under the varnish they appear to be covered with moss. Since the small crystals throughout must be orientated according to the main crystal, they are cut by the globe surface at different angles in different parts of the globe. Already at the edge of the small squares they will no longer lie horizontally, but will stand out inclined to the surface. That part, shown in Plate V, is still a good way within the edge of the square, and yet the small crystals, arranged in well-defined rows, peep only with their edges above the surface. Towards the boundary they become more and more rare and are progressively more deeply buried, until in the icositetrahedral face they gradually disappear completely. Outside the squares the surface appears perfectly smooth even on enlarging 250 times; on the octahedral points, which can be clearly recognized under the microscope as dark points with greenish colouration, no trace of etching can be discovered. And yet the whole of the smooth octahedral surface reflects with its delicate glow, its flowing glitter, the hidden crystal. That means that even here the etching must have had its effect and the fine structure must have been revealed by the submicroscopic crystals.

The crystal faces appearing on the sphere are throughout reflections of minute etch-figures. From the orientations of the uncovered crystals, anchored in the single crystal, the lattice planes, whose properties show up on the surface of the sphere, should be capable of being determined by purely mathematical considerations. The mathematical theory of the crystal sphere should make it possible not only to calculate the size and shape of the faces which actually occur (*e.g.* cube—and icositetrahedral faces), but also to calculate any given crystal faces, *i.e.*, to predict by drawings those which in reality have not yet been produced.

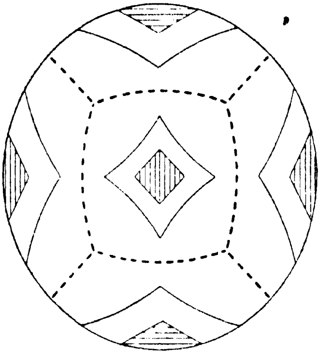

Fig. 52. Cube scheme.

One type of plane can of course be drawn on a globe without difficulty. If for instance only cube faces (without the icositetrahedron) appeared, the shaded sketch of Fig. 52 would be formed. The octahedron faces alone (Fig. 53) would on the globe have the shape of spherical triangles (two of their sides would appear as straight lines on the diagram, whilst the third would be a quarter-circumference). The rhombic dodecahedron, shown as a crystal form in Fig. 25 (p. 100), consists of twelve faces extending between the mid-points of the squares to the octahedral points (Fig. 54). These simple configurations are

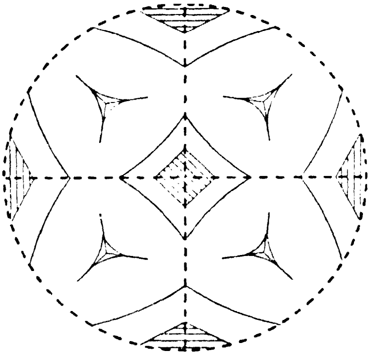

Fig. 53. Octahedron scheme.

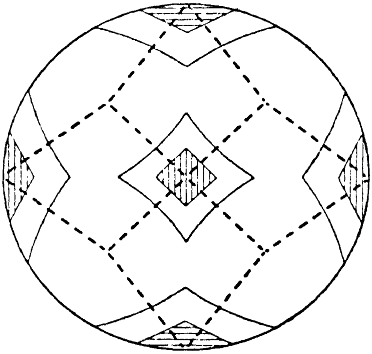

Fig. 54. Rhombic dodecahedron scheme.

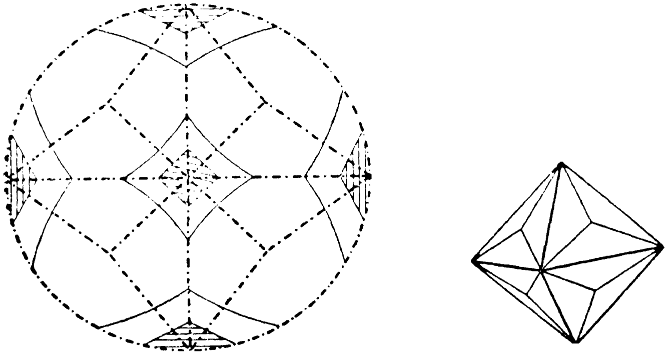

Fig. 55. Triakisoctahedron scheme.

actually formed on three single crystals of copper, which are reproduced in the essay by Hausser and Scholz. The triakisoctahedron (octahedron on whose faces triangular pyramids project) is dotted in in Fig. 55, the icositetrahedron (cf. Fig. 27, p. 101) is shown schematically in Fig. 56. The forty-eight-faced form (the shape of the crystal in Fig. 24, p. 100) appears schematically drawn as a combination of the two last-named forms (Fig. 57). Tetrahexahedra (cubes

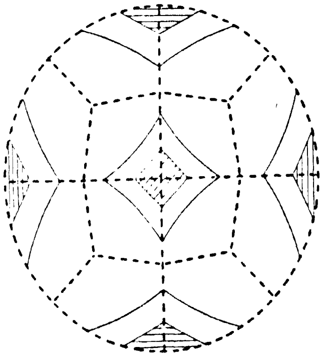

Fig. 56. Icositetrahedron scheme.

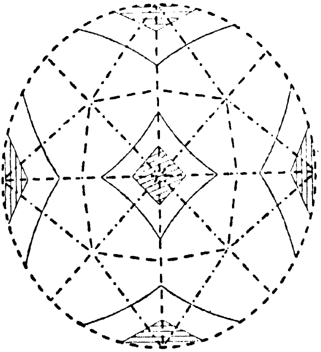

Fig. 57. Hexakisoctahedron scheme.

with four-sided pyramids) project in the centre field with their cube edges as curves, the pyramid edges as straight lines, and *vice versa* in the four adjacent fields (Fig. 58). The pentagonal dodecahedron, or pyritohedron, which consists of twelve symmetrically

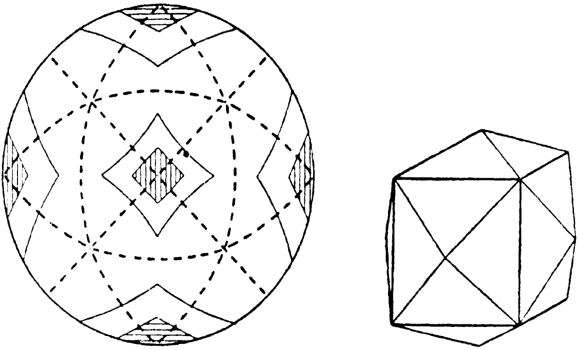

Fig. 58. Tetrakishexahedron scheme.

built and symmetrically arranged pentagons, fits clearly and simply into the globe scheme (Fig. 59), and the twenty-four-faced diakisdodecahedron appears as a pyritohedron whose faces are symmetrically halved (Fig. 60).

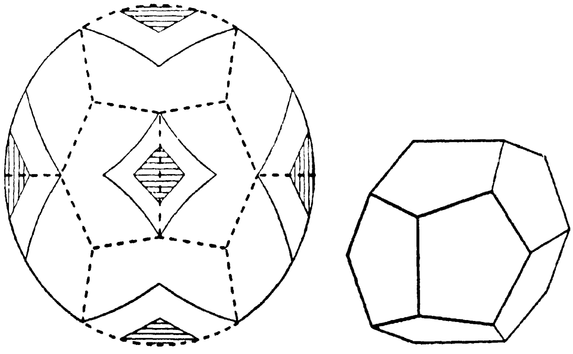

Fig. 59. Pentagonal dodecahedron scheme.

The intersection of cube, icositetrahedral and octahedral faces can be seen on our crystal sphere. What intersection figure will be given by any combination of faces can not be known as long as the theory of the crystal sphere has not been formulated.

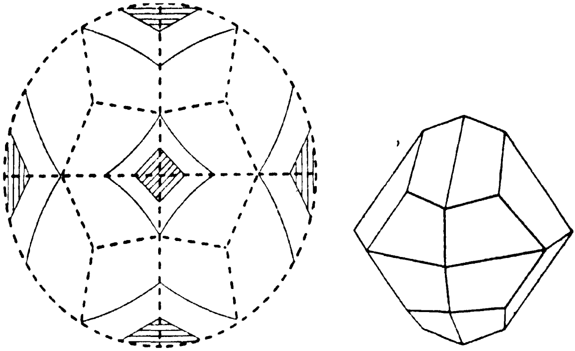

Fig. 60. Diakisdodecahedron scheme.

Unfortunately the sphere on which the seven holohedral forms of the cubic crystal show up, has not been published in the essay of the Siemens Co. because of the complication of the drawing. Further, some questions which might have been answered by mere measurements on existing crystal spheres have remained unsolved. It would be interesting for instance to know—this can not be gathered with certainty from the illustrations of the above-mentioned essay—whether or not the size of the cube face is influenced by the kind and number of the other faces, which appear at the same time. In their diagrams 18 and 19 the cube squares appear to be equally large, although the second globe shows, in the middle of the octahedra, regular hexagons as reflections of the hexakisoctahedron, which are completely absent on the former. On the other hand the squares are apparently smaller in diagram 22, and they are more curved in diagram 18, although on both globes the icositetrahedral face seems to be manifest, though with unequal strength. However, as long as these and similar questions have not been solved, one can not think of putting forward a theoretical crystallography of the sphere.

Now if all planes valid in the cubic system were pictured on the sphere, what a rich kaleidoscope of spherical planes would be formed! Would not at every turn of the crystal, at every change of illumination, since each face shines in its own way, a flood of changing reflections play round the sphere? Would not the mirror-like globe become intangible to the observer, would not its bulk completely disappear behind the fascinating play of the light?

And that is actually the case on our crystal globe. A glitter bright as glass, a silky glow, would make it appear incorporeal and one would think one could glance unhindered into its interior, as though it were transparent, or even a play of fantasy. At a slight turn, however, out of the glowing flux emerges a softly-glittering body, a cube, with rounded edges and corners, and leaps to the surface. Swelling forms glide intangibly under the surface and disappear in the crystalline element. The dark eyes of the cube faces are often covered by a non-transparent, but flowing glitter. On close examination they can suddenly rise up with incredible sharpness like shining, polished obelisks with conically curved faces. The square frames glitter in certain positions like sparkling gold.

And further, water-clarity, and brilliant varieties of colours stand next to each other, and at every turn they change their shining appearance. In all probability one can never see the globe in its real shape, but only as an indefinable formation of bulges and cavities, resting and hovering faces, now glowing with friendliness, now with magic, as though light itself had formed into a globe, and as though it played a teasing game with the eye. Sometimes a misleading glimmer looses itself completely and appears to be floating outside the sphere, between the light source and observer.

It is quite impossible to describe in words the play of light and shadow, but equally impossible to record it photographically. Our pictures furnish only a weak reflected splendour of reality, although much trouble and care was expended.

In homogeneous illumination (Plates VI 1 and VII 1) the globe appears with a glass-like gloss, almost transparent and unreal, suspended in space without effort. In powerful light, however, the strangest reflections are evoked and produce a charming glimmer.

Photograph I of Plate VI, (view on to the rhombic dodecahedral face) illustrates the globe surrounded by a mirror-like frame, with the octahedral points as a feeble glimmer. In the next photograph (VI 2, perpendicular to the cube face) the shape of the globe is apparently deformed, the square stands out with conspicuous brightness and power. In VI 3, the same view, the cube face appears dark, and receding into the globe, but the icositetrahedral faces on the other hand appear with a brilliant gloss. In VII 1 the four octahedral faces hover like shadows round the spherical square, whilst the four surrounding cube faces at the edge of the globe glitter faintly. VII 2 and VII 3 show the same view for the observer and still the icositetrahedron lights up here, and there the rhombic dodecahedron sends forth its rays, like a butterfly, with fairy-like glow. On Plate II, however, the whole sphere smiles at us like the radiant face of an animal.

The question now arises: how can all these curious apparitions be explained? The surface marks can be explained by the reflections from the small etch-crystals. But in the lighting up of different crystal faces the extraordinary facts about the crystal sphere are not exhausted! For even where no markings can be seen, the surface does not appear like an ordinary copper sphere, even if it were etched. There—as one might say—an unnatural, imposed glow has been poured over the whole sphere; every part acts as an uncontrollable mirror, every point as a source of inexplicable shine. The crystal reflections actually are the least puzzling, in fact they are coarse—not to say shallow—facts compared with the charm which flows from the unspecified, loosely-flowing faces. Whence comes this incomparable play, the enchantment of the whole globe surface?

No, more is happening here than can be grasped by the means of crystallography. The eye would have to be utterly obtuse, if not blind, if it were not to notice that the feverish glitter of the sphere reflects a final secret. It is not the cube, not the octahedron, nor the rhombic dodecahedron, nor any lattice plane of the crystal, it is the crystal itself, the crystal as a unit, which makes the sphere appear enchanted in broad daylight, and magically illumined.

The well-known planes, which occur in the habit, which reveal themselves in cleavage and percussion figures, which show up in etch-figures, and which can be reflected by X-rays, are only the comprehensible foreground of the crystal, the front which it shows to scientists, not its internal character, which can be neither drawn nor calculated. Even the sober mineralogist must admit that in the lattice there are not only the known and named crystal planes, but beyond them innumerable others, in fact an infinite number of planes, which must have an influence. All one has to do is to draw a rectangular or oblique net and to imagine it extended indefinitely and to draw from one point a straight line in the direction of any other point of intersection. There are then from one single point an infinite number of possibilities in that plane and an even greater infinity in three dimensions. Cube and octahedral planes, etc., only join adjacent points, but should all other directions be non-valid, because they do not appear in the habit, and can not be exposed by other means either? Here, in the mirror of the crystal sphere, they all actually appear and produce a vitality which can hardly be grasped. The small numbers of the indices can not exhaust the crystal, they grasp only the mathematical outer aspect. Only when considering infinity can one intrude into the inner crystal. Then numbers cease altogether, and out of the infinite multiplicity arises a single unity which can no longer be expressed in numbers. This unity greets us in the crystal sphere, it glows at every point. In this strange shape awakes the innermost crystal; the sphere has brought it to life. Only now does it reveal its essence, which with our own eyes we can not measure, but only glance at. And it is the unutterable and the divine, which shines towards us.

"Ein stein hât ouch minne unde des minne suochet den grunt."—MEISTER EKKEHARD.

PART THREE

MATTER

Introduction

FROM the definition: "Bodies are spatialized matter", it follows necessarily that matter as such can not be spatial; for as soon as it is spatial it must already be a body. The body, however, is such an intricate, insoluble unification of matter and space that neither space nor matter can be found directly in it. If one searches for space in a planed piece of wood or in a crystal, one at once comes up against the very things which seem to be not space but matter: the solidity, the tangible, the unpierceable, that which fills space. Space itself, however, appears nowhere without matter. For the annual rings are made up of fibres, the latter of finer structure particles, but not of space, which is distinct from matter. Conversely, if in the same body we seek matter we shall meet many structure particles which are determined spatially and which keep matter enclosed within themselves, so that at no point does matter reveal itself to us. In short, the body is nothing but structure which represents itself as fullness, *i.e.*, as material, when we seek space, and as division of space when we seek matter.

The spatial side of structure, the lattice, has been examined more closely in crystals and we have exhaustively found all possibilities in the seven crystal systems, or rather in the thirty-two classes of symmetry. We have frequently met with the substance without being able to grasp it. It bears and feeds the crystal, and yet can in no way be found in it. It is the source of all bodies, in which it is revealed and hidden at the same time. Since it is itself not spatial it can not appear in bodies which are always spatially extended.

If one wishes to approach matter one must not divide bodies as such into progressively smaller parts, since one is just as far from it in the smallest particle, even in the atom, as in the whole crystal. One must in fact separate space from matter in order to be able to recognize it by itself. This is performed by progressively robbing the body of its spatial qualities until something entirely lacking in space remains.

CHAPTER ELEVEN

THE HIDDEN UNITY

The Weight

THE most perfect body, the purest representation of space, is the crystal: matter has been completely superseded in it, *i.e.*, must have disappeared entirely. The forces within the crystal, and therewith those of space, can be broken down through all degrees of aggregation to the colloid. In the gel matter appears less repressed owing to the indeterminancy of spatial formation; it appears more or less free. But is not the gel, although undefined and changeable, also still extended spatially? And can dimensions, normally a property of bodies, belong to matter itself? What we see in the gel is therefore always spatialized matter, and therefore not matter itself.

To obtain free matter, we must release it entirely from space. And still more; we must release it not only from space, but from all those properties which are in any way connected with space. Size and shape are directly determined by space. The gel no longer has shape, but it has size, and also a certain consistency, hardness and elasticity. Hardness, elasticity, viscosity, etc., are still, however, properties of bodies which tend to preserve shape and size; they must disappear if matter is to appear by itself, for matter by itself is neither hard nor soft, neither elastic nor the opposite. But it can not even possess a colour. Colour may be a property of matter, but it is at the same time a property of bodies, which can only appear together with matter in space, and whatever appears in space can not be attributed entirely to matter, which must be dissociated from space. The same applies to heat, light, electricity, and magnetism; all these properties depend on bodies and do not appear by themselves. There are only warm or cold bodies, but there is no cold space (which is otherwise empty) and still less is there cold matter by itself. It is only when we do not consider *physical* properties that we may hope to approach matter.

What then remains? No actual body, but something which conceals itself behind bodies. Physico-spatial properties all belong to bodies themselves and are unable to disclose the appearance of matter. What properties are then due to matter itself?

There is a science whose purpose it is to investigate matter itself: this is *chemistry.* Spatial characteristics of bodies may serve for their determination, but chemistry deals with properties which occur quite independently of space; these are chemical properties in the strict sense of the word. Matter itself and no longer the body appears in them.

The most important and fundamental property of matter, for all real chemical phenomena, is the affinity, the preferential attraction or chemical relationship. Sulphur, S, and iron, Fe, combine on heating to form a new body, iron sulphide, FeS, which is neither sulphur nor iron nor the sum of the two, but represents something entirely new and appears in the form of a complete unity with properties as equally independent as those of its two constituents. Here, matter itself speaks. The fact that sulphur always combines with iron in the same way and in a certain definite proportion (approximately 4 : 7 by weight) must be part of its essence. Sulphur does not combine with all substances which we know, but it combines with most elements, *e.g.*, with oxygen, O. The compound SO_2 (sulphur dioxide) had independent properties from oxygen and from sulphur, in fact only those properties characteristic of itself which can not be explained as the sum of the two sets of properties. But sulphur and oxygen also combine in a certain definite proportion by weight (32.1 : 32) to form SO_2. This relationship between sulphur and oxygen can not be regarded from a purely spatial standpoint. For sulphur dioxide at normal temperatures is a gas of pungent odour, and liquefies at —10°C. to form a liquid as clear as water. This means that spatial relationships can change without change in relationships of matter. Only by some other affinity of matter could its spatial relationships change again. If, for example, sulphur dioxide is dissolved in water, an acid is formed of chemical formula H_2SO_3; the dioxide does not remain indifferent to the water, but is drawn into a new combination with it. By boiling, however, sulphur dioxide can be driven off from the water. The affinity which combines sulphur with oxygen is therefore stronger than that combining sulphur dioxide with water. Further, this compound is formed when sulphur is burnt in the air: $S+O_2=SO_2$. Even this preparation demonstrates the independence from spatial relationships; on the one hand the solid sulphur combines with gaseous oxygen, on the other this compound originates from an aqueous solution.

We have, therefore, in the chemical relationship a direct property of matter, *i.e.*, a property which belongs to matter without the interference of space. It is rooted not in bodies but in matter itself. One would therefore expect that affinity would enable one type of matter to be distinguished from the other; for in this property matter expresses itself directly and shows us its true aspect. Yet, this is not quite the case, for the curious fact exists, that sulphur can combine with oxygen in a different proportion, 32.1 : 48. The new compound, sulphur trioxide, SO_3, also has certain properties characteristic of it; it is a colourless mobile liquid which is converted into a vapour not at —10°C. but at +46°C., and on cooling it solidifies into an ice-like, transparent solid which melts at 15°C.

Even preferential affinity, the most fundamental expression of matter, is therefore not absolutely unambiguous, but it changes rather like the physical properties (hardness, density, state of aggregation, etc.). Such change does not occur merely as exception, but is so frequent that the relationship of elements no longer appears as a definite but rather as a somewhat changeable property. Two units of weight of hydrogen, H, combine not only with 32, but also with 64, 96, 128 and 160.5 units of weight of sulphur, (H_2S, H_2S_2, H_2S_3, H_2S_4, H_2S_5). And every one of these compounds is characterized in its properties by the formulæ without ambiguity.

But if hydrogen and sulphur combine in five different ways to form different substances, *i.e.*, if their relationship can be expressed by five different degrees, is it then still a determined property of matter? Is it not rather an analogy to bodily appearance in which also matter, without showing its most characteristic aspect, expresses itself? Hydrogen is manifested by its relationship with sulphur and at the same time hides itself by the changes possible in this relationship. As soon as proportions in weight change, matter, which must be assumed to have some veiled but definite being, becomes intangible again and retreats completely into the abstract.

One must be clear that chemistry is in reality a very abstract science which in its experiments with matter appears to be connected with it much as the art of cooking is with the preparation of dishes. On closer inspection its compounds are no less far removed and intangible than are for example energy, electricity, light, etc., to the physicist. The chemist has directly in front of him nothing more than images of properties whose carriers never appear. Size, shape, hardness, density, colour, state of aggregation, temperature, in short all that which we can grasp, determine, or measure, change in front of our eyes according to the conditions of the experiment, or even with time alone, so that there may be difficulty even in recording the pictures seen. And even these pictures fluctuate constantly in front of our eyes and they must, as images of matter, which casts them forth, be regarded rather as imaginary than as real pictures. As here, where an imaginary picture appears, where in reality nothing exists, and where one reaches into empty space, so the chemist can not grasp the changing manifoldness of matter in its reality; no one has yet seen or grasped H or O, as something permanent, something identical within the change of appearance. It is precisely matter, with which alone we are dealing, that is always as hidden as the "thing in itself". What the chemist realizes is merely its image, not its true character. And now, as we have seen, even chemical relationship, the equivalence of matter, changes and thereby also becomes a mere image. It may be, since the picture does not appear in strange spheres (in space) but on its own ground, that of matter, that it should be taken as the real one, but it is still only an image and not the reality of matter.

And yet the chemist assumes behind all these changing real and imaginary images a single and unchanging type of matter; he names it and records it by a conventional symbol. What courage of abstraction is taken in this subject is obvious. One can not even smell or taste matter by itself, for these properties may change, without the chemist changing the symbol. It may be that he writes (in order to differentiate clearly), O_2 for the ordinary oxygen which does not smell, and O_3 for ozone, which has a strong irritating odour, but it is precisely the O which is the secret lying at the foundation of oxygen and ozone. P remains P whether it is phosphorescent and poisonous as in white phosphorus, or whether it does not phosphoresce, does not ignite spontaneously, and is nonpoisonous, as in red phosphorus. Sulphur occurs in a tremendous variety of appearances and is still referred to by chemists as one and the same matter with the symbol S.

Such manifoldness occurs not only in elements but also in compounds. The above-mentioned sulphur trioxide, which below 15°C. appears as a transparent solid, changes when kept for some time into a non-transparent, white, asbestos-like mass which on heating does not melt, but vaporizes directly. Both forms are described by the chemist as SO_3. But it is just this basic type of matter which does not appear at all because it appears in two distinct forms. In these allotropic modifications, what applies fundamentally to all matter of chemistry, becomes remarkably clear; that matter remains hidden behind the play of phenomena, in fact it *can not* appear at all.

Why is it then that the whole of chemistry is not a science of superstition? What is it that permits chemistry to deal with matter in reality, matter which is unapproachable by it and hidden from direct perception by a flood of false images? And how can we hope to prove the presence of matter and conceive it in the form of images which can not represent its essence? If even affinity is no longer reliable, how can we grasp matter, how describe it? What is it that gives to the chemist his certainty and a validity to his science?

It would have been in fact a disaster for chemistry, which would never in all probability have risen above the level of alchemy, if it had not learned to use a simple but definite tool: the balance. For the only really dependable phenomenon in the world of matter is its *weight*. Only the weight gives the possibility of determining whether anything has been added or taken away and with the help of weights one can grasp matter itself. If a piece of magnesium burns with a glowing white light there remains in place of the firm metal only a little loose ash and from the appearance one might think that this was but the unconsumed residue, everything else having disappeared. The balance, however, proves that the ash is heavier than the original metal, in fact that nothing has disappeared, but on the contrary something, namely oxygen, has been added. If one has matter sealed up in a glass tube and if one allows it to pass through all kinds of changes, the balance shows that through all these changes of appearance the weight has nevertheless remained unaltered. Since nothing can have been added or subtracted it must still be the same matter, however much its properties may have changed before our eyes. Since then nothing has remained the same except matter and its weight, the latter is not a property like all others, but is directly attached to matter and it can only grow and disappear with it. Weight is admittedly not matter, but it is, as it were, its double, its unchangeable shadow in which one can not see, but can at least measure matter itself. If matter exists then its weight must also exist; if there is weight there must be matter. The two are quite inseparable, the shadow is a certain sign of reality. If we have a "rare gas" in the tube which we can not see nor smell nor taste, which we can not even prove to be present by chemical reactions (rare gases do not in fact form any compounds) the weight proves its presence beyond doubt. Weight is the voice of matter. Only in the weight can it be recognized directly and it is the only direct sign which matter gives us. Since we never have matter by itself, but since its weight is a true representation of it, the chemist in fact takes this representation as the original and classifies these representations, *i.e.*, these weights, instead of matter itself. Only according to the weights can elements be classified unambiguously, and the equivalent weights are the only firm foundation for the so-called "periodic system" of chemical elements. With the help of "atomic weights" alone one has represented the properties and one has gained by the vertical groups some perspective. Without weights the whole periodic table would collapse. The fact that it is not perfect in its structure can not be due to the equivalent weights but only to the other less dependable properties. Weights in fact are as fundamentally clear as the mathematical relationships of the crystal. The atomic weight, however, has not only made possible the construction of the system, but the prediction of elements still unknown, some undiscovered even to-day. The fact that they exist and to what places they belong appears clearly from the structure of the system. The weight has opened up the world of matter and has shown us its inner order. The periodic table is the non-spatial sphere of matter, as the crystal systems and symmetry classes are in the realm of crystals (the world of space). To the thirty-two classes, examples of two of which are still unknown, there correspond ninety-two elements, of which three still await discovery.

What are the equivalent weights? They are not absolute, but relative numbers. They indicate in what proportion by weight the different elements combine with one another. If one denotes the smallest equivalent weight of oxygen as 16, that of hydrogen becomes 1 that of sulphur 32.1, that of gold 197.2, that of uranium, the heaviest element, 238.2. The symbol H means, not merely the element hydrogen, but at the same time its intangible double, the number one. S, apart from extremely changeable sulphur, means the definite number 32.1, etc. The elements are characterized therefore only by their numerical relations to one another. This is another indication of their unspatial nature. For how can we determine the absolute weight of oxygen, O, since a certain volume at a definite temperature has not only a changeable weight, but even at the same temperature can show weights which are in the proportion 2 : 3, according to whether O_2 or O_3 is present? In itself every element is to a very high degree changeable; it is only the proportion of elements to one another that is fixed or more precisely, the smallest (relative) weight in which they are combined.

The equivalent weights are definite numbers which tell us something characteristic about the elements. H is characterized definitely by 1, O by 16, S by 32.1, Au by 197.2. These numbers express the relations of the elements as matter, not as bodies. They unveil for us the first, though not the last secret of matter.

How is it then with the weight itself? Can we define the absolute weight of every element, just as the equivalent weights, *i.e.*, can we determine which weight corresponds to S to distinguish it from O, Au, etc.?

The "specific" weight is certainly a quantity which we can determine for every type of matter. By this we mean the weight of a unit volume (perhaps a cubic centimetre) of that type of matter. For copper this is about 8, for iron it is 7.5, for gold it is 19.25; that is to say, copper is 8 times, iron 7.5 times, gold 19.25 times as heavy as water. Have we not already admitted that the specific weight is not an absolute, but again only a relative weight? Further, the relation expressed by these numbers concerns in reality not matter but bodies. One cubic centimetre of iodine for example can have different weights according to whether it is solid, liquid or gaseous. (Iodine melts at 114°C. and boils at 184°C.). The element I can not therefore have a definite specific weight although it is identical with itself through all these changes; the same applies to S, Cu, etc.

The specific weights must belong entirely to the world of bodies, to the spatial, and have no concern with matter itself. The unit weight (the gramme) is defined already by a certain volume (1 $cm.^3$ of water, at 4°C., *i.e.*, it depends on wholly spatial and physical conceptions.

What we seek, however, is the weight which characterizes the I, the Cu, and the Au under all circumstances: a number which can be ascribed to the element—similar to the equivalent weight—once and for all; for only such weight would no longer depend on the body but on matter, and would unveil a new aspect of its character.

Science can in fact tell us about such numbers, the absolute atomic weight. For H it is 1.6 × 10^{-24}, for iodine, therefore, it is 126.9 × 1.6 × 10^{-24} gr. Every element has its definite unchangeable atomic weight, every compound its molecular weight, which is not founded in the physical body but in matter itself. But are these, strictly speaking, absolute weights? What does 1.6 × 10^{-24} gr. really mean? Merely that the hydrogen atom is 1.6 × 10^{-24} times as heavy as a cubic centimetre of water at 4°C. And the iodine atom is therefore again 126.9 times, the gold atom 197.2 times as heavy as the atom of hydrogen. Are these not again relative weights, numbers which matter possesses not as such but only in relation to other matter? But these relationships do not even remain in the purely material world like the equivalent weights but they are, at least by virtue of the unit weight, linked to bodies. It is by no means senseless but almost essential to ask: If the H atom weighs 1.6 × 10^{-24} gr. what is the weight of one gramme?

What do we understand by one gramme? The physicist says the weight of a unit mass. Twice the mass weights 2 gr., ten times the weight 10 gr. What is "mass"? It is nothing, a conception without essence, a shadow without essence; the shadow of the weight. If a body is twice as heavy as another the physicist ascribes to it twice the mass. The weight is the cause of the concept "mass", mass is not the cause of the weight. Mass is a purely mathematical and physical conception and it is by no means identical with matter or substance. Mass lacks not only all properties but it has no essence apart from weight; it is nothing but the weight itself, described by another name and given to bodies. Only because bodies have different weights has one given them "mass" with which we can calculate in the same way as with weights.

What therefore is a gramme? A very definite weight though definable only by bodies. And what is weight? Nothing but the fact that every body, whether solid, liquid or gaseous, is attracted by the earth and is held to it. Even the atmosphere, that delicate sheath which gradually rarefies towards the outside, remains tied to the earth for millions of years. It is this attraction—and not an inert mass without a will of its own—which is the cause of weights. For if a body lies on the ground or on some other base it applies pressure by virtue of the attraction of the earth. It is this pressure which we call weight. The weight is therefore a frustrated, arrested motion, and the will to move is its actual nature. If we are to determine the weight, not according to the gramme, which will only give us a relative number, but according to its own measure, we must measure that arrested motion. Only when falling freely in that motion does the body disclose the secret of its weight.

The force which draws the body towards earth is called *gravity*. This and nothing else is the final cause, the true nature of the weight. We must measure gravity in order to determine the absolute weight. But the force can not be measured directly but only by its effect. Since the weight, which reveals the latent force, does not lead us away from the vicious circle of relative numbers, the free fall alone can serve as an absolute measure of gravity.

The greater the force the greater is the velocity caused by it. A body when falling freely does not show a constant but a uniformly increasing velocity. This acceleration on falling freely (the constant g) is 980 cms./sec./sec. Since according to a universal law the acceleration is in a simple proportion to the force the *gravitational acceleration* is the direct indication, the real aspect, the proved measure, of gravity on earth.

What is gravity? From what sphere does it originate, and how deeply is it anchored in bodies?

A piece of sulphur falls in the same way, with the same acceleration, whether it is hot or cold, whether solid or liquid, crystalline or amorphous. The same applies correspondingly to iodine, copper, gold, in fact to every element. And if we were able to isolate from the iodine—or sulphur vapour a very small particle (even an atom) it would fall to earth with exactly the same velocity and in the same direction as a piece of the same material as large as a fist or as large as a mountain. Admittedly the motion must be perfectly free, that is to say it must not be affected by anything, not even by the resistance of air. For the elements the following law holds: the free fall is entirely independent of all physical properties and even of the mass of the falling bodies.

In the same way as elements, all compounds, alloys, and mineralogical aggregates, the grain of dust and the block of rock, in short all real bodies, organic and inorganic, fall towards the earth. If now the velocity of fall of a body is independent of the physical or spatial conditions then iodine does not fall as a solid, liquid, or gaseous body, but only as iodine. For nothing but the iodine itself remains unchanged throughout all variations of conditions. It is not because iodine, gold, or copper are bodies that they are drawn towards the earth, but because in the depth of bodies, behind their structure and the manifold appearance, there exists unchangeable matter, the I, Au and Cu. Matter, not the body as such, is subject to gravity. If the body itself was the cause of the attraction then together with it the attraction and with it the velocity of fall (or the direction) would have to change. In reality, however, the bodies can change through all sorts of conditions, from the hard crystal to the invisible gas, from a heavy mass to the finest particle (atom or molecule); the acceleration g remains unchanged and signifies matter which is hidden in the crystal as well as in the atom.

But this does not exhaust the secret of gravity. Not only is the acceleration with which iodine falls as I, gold as Au, diamond as carbon, C, calcite as $CaCO_3$, always the same, but the velocity of fall is the same for iodine as for gold, for diamond and calcite, for a fibre of wood, and for an atom of hydrogen. In short the well-known law of physics holds that "all bodies fall with equal velocity"; a piece of paper does not fall differently from an iron nail or from a lead shot. If iodine falls equally as fast as gold then it must be attracted by the earth with equal force. But if iodine and gold are attracted in the same way then neither iodine nor gold can be attracted as such. For otherwise different types of metal would result in a different force, and it is exactly this that is not the case. Gravity, therefore, does not take hold of any existing matter as such but affects it in something which is common to all, and which is hidden behind the variety of elements as matter is hidden behind bodies. It calls for that unity which is neither iodine nor gold, nor any other element, but it shows us in every one of these only one side of their nature, a new aspect. Matter is a mere form of that unity which underlines them all and binds them to that unity. It is this unity which is the nature of matter in itself, which we may term for short *the substance*.

The substance (to put it clearly) is the innermost and last stage we reach in the search for matter. It is not definite matter but it underlies all matter, being its nature and its unity. Real matter is nothing but the expression of substance, its children, grandchildren and great-grandchildren up to the millionth generation. Since it is not even matter it is still less a body. In this manner it is "in itself" not bound to matter or bodies in any way and does not know of chemical affinity. For no projection, no section of the real world, reaches the final basis of being, substance. In itself, it is always hidden, at no point of the universe can it be found. Substance was the unity which existed before space and time. How shall we grasp it? That which always changes and varies is an image of space and matter. Substance remains unaltered, eternally only itself. All matter rests within it. It causes all infinite manifoldness and remains nevertheless itself. In spacing everything is isolated and varied, but in substance everything is an undivided uniformity. In itself it is the unity apparent in the universe.

CHAPTER TWELVE

THE DIVISION OF SUBSTANCE INTO ISOLATED ELEMENTS

SPACE isolates things sharply from one another; it changes matter into structure and binds it to the world of bodies. Had it been the absolute master, it would divide everything into discrete points and would form them into crystals. In space things exist separated from one another.

The substance, as far as it is superseded completely, as in the crystal, forms the link and brings matter into contact. It is the keeper of the unity in a divided world. Bodies exist with apparently complete indifference to one another; as matter, however, they are not isolated, but search for one another, interpenetrate, and melt into one another. No matter is completely separated. Even the most sluggish "rare gases" which form no compounds mix with other matter and can not remain alone. Gases are dissolved in liquids, liquids vaporize into the atmosphere, solid bodies decay, melt and dissolve. Even the hardest body has a vapour pressure, though not always measurable, and even the coldest ice vaporizes and thus mixes with its surroundings. Everything diffuses and is in a state of mixture and interpenetration. Considered as matter, things tend to melt into a unity.

At one time one ascribed to chemical elements love and hatred, and thought that one could thereby explain all phenomena. But matter knows only of love, admittedly to a varying degree. It tends towards uniformity and strives to attain equilibrium since that uniformity can never be reached. All chemical phenomena are an approach to this equilibrium.

Sulphuretted hydrogen, H_2S, dissociates in a red-hot tube into the two elements hydrogen and sulphur. But under the same circumstances hydrogen and sulphur can combine to form sulphuretted hydrogen. Both reactions take place only until an equilibrium is attained between the elements and the compound. If water vapour, H_2O, is led over red-hot iron, Fe, it attracts oxygen, O, and hydrogen, H, is liberated: $2Fe + 3H_2O = Fe_2O_3 + 3H_2$. If, vice versa, iron oxide, Fe_2O_3, is heated in a current of water vapour, the hydrogen draws the oxygen from the oxide and forms water. The same equation applies, therefore, in reversed form: $Fe_2O_3 + 3H_2 = 2Fe + 3H_2O$. The two reactions, again, take place only until a state of equilibrium is reached. Mathematical formulæ have been found according to which the equilibrium for all chemical processes can be determined. When gases are dissolved in liquids a state of equilibrium is also reached. Iodine dissolves only sparingly in water but freely in carbon disulphide. If water and carbon disulphide are added to one another (they do not mix) and if then iodine is added, the iodine independent of the quantity used dissolves in the two liquids always in the proportion of one part in water to two hundred parts in carbon disulphide. Thus there is an unceasing motion in the world of matter and complete equilibrium can never be reached. A deep gulf which can never be bridged divides the elements from one another. The substance, the pure uniformity, is broken and has branched into ninety-two *elements*.

This first "dismemberment" of the "uniformity", in the sense of Spann* will always be surprising and incomprehensible. For this is in strictest contradition to the nature of substance and nevertheless can be attributed to it as the first step towards revelation. The elements, which appear as relative numbers, are divided from one another not by space, but by the law of equivalent weights alone. Nitrogen and oxygen are mixed in air in the proportion of 79 : 21 by volume, but they can mix in any other proportion; as soon as they combine, however, only the following proportions hold: N_2O, NO, N_2O_3, etc. No other proportions are conceivable. But even the metals can mix at will and can penetrate into one another and form real solutions in the solid state (alloys): *e.g.*, brass (zinc and copper), German silver (copper and silver). That is to say, space does not divide these from one another, but allows them to flow undisturbed into one another; on the material side only, a gulf divides them bridged by the narrow plank of equivalent weights.

The substance therefore breaks up the complete unity from the very first by mathematical division. And this cut is unsparing and without its like in the world of matter. For as soon as the elements disclose themselves, *i.e.*, as soon as they undergo a chemical reaction, they combine only in very definite proportions, and not arbitrarily as would correspond to spatialized matter. Water and alcohol can be mixed in all proportion, common salt dissolves in water to an extent until saturation is reached. Hydrogen and oxygen, however, can not combine in any other proportion of weight than 2 : 16 to form H_2O, sodium and chlorine in no other proportion than 23 : 35.5 ($NaCl$). The reagent which is in excess does not take part in the reaction. And even though the possibilities of combination may be manifold (as between nitrogen and oxygen) these relationships remain distinct with all mathematical correctness. Only the two definite numbers ($N = 14$, $O = 16$) or their multiples can occur, an incredible selection from the unity of substance. It is as though the unity could only reach variety by contradiction of itself. Just because substance appears in all stages of variation, the first step out of its own self means at the same time the destruction, even the negation, of its own nature. The first matter, the element emerges, and with it the number. It is not important at this stage whether the equivalent weights can ever be found exactly by numbers or whether they can be so expressed at all, but the fact is vital that they are fixed and therefore have the character of exact relative numbers.

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*Othmar Spann, "Kategorienlehre" (1924) and "Schöpfungsgang des Geistes" (1928).

From the substance the number has originated together with the element, a secret which finds its counterpart only in the geometry of crystals. The number in the form of equivalent weights exists in the non-spatial, but that of the symmetry relationships is in space. Only the latter are comprehensible, because they lie in the structure of space, the former, however, are entirely incomprehensible as being in contradiction to their origin.

And even so; how could the unity open up in any other way but in numbers? The substance could not merely have been discharged into real space in arbitrary amounts, as can light. Light hurries along nonmaterially through space like "ein Mädchen aus der Fremde", touching it only from the outside; in the body, however, substance conforms to space and combines with it, thereby creating the universe. Since substance is not itself spatial it can not appear geometrically, for geometry belongs to space alone. In order to meet space mathematically the substance appeared in non-spatial proportion, in a number. The number is the aspect which it shows to space. By numbers (the equivalent weights) the substance has entered space to give itself up to the perfect crystal.

But now the elements show emotional feeling for one another, frequently until they are white-hot or even explode, simply because they are clearly divided and are still children of substance. Unity is their nature and division their realization, their life. It is no wonder that they join forcibly on the narrow basis of equivalent weights in order to become a unit. And only in that aspect are they emotional, otherwise they behave gently to one another. Internally, on the side of substance, they have lost the unity and their equilibrium and therefore they leap into chemical processes; from the outside, the side of space, they conform to continuity (in solution and mixture, diffusion and alloys) and constantly re-adjust the equilibrium, even in chemical reactions.

CHAPTER THIRTEEN

GRAVITATION

The Universe

THE chemical elements and their reactions are the first and innermost aspect of substance. In them the unity is expressed only by numbers. Matter now interpenetrates progressively into space and builds the range of bodies from colloid to crystal. The entire universe of spatial matter is built up of equivalent weights, which are the first rupture of the unity of substance and lead to the variety. The unity itself can never appear directly in this world but only in broken images.

Gravity alone, which transcends the distinction between elements, must lie in deeper depths. It is a direct expression of substance, its only direct manifestation. Can one calculate gravity? Can we see the number by which it is expressed, and thus comprehend the cause of all being? Is the possibility given to us that substance itself can be grasped intellectually?

We have regarded the acceleration due to gravity g as a definite measure of gravitation. But closer inspection shows us that this acceleration is not a quantity which can be unambiguously determined, but is a number which varies even on the surface of the earth. Above all, it alters with geographical latitude in such a way that it shows its greatest value (ca. 981 cm./sec./sec.) at the poles and the smallest value (just over 977 cm./sec./sec.) at the equator. The fact emerges clearly that gravity changes with the distance from the centre of the earth. Since the earth is known to be somewhat flattened, the poles are at the least and the equator at the greatest distance from the centre. The general law states that gravity (and with gravity the acceleration of fall) is inversely proportional to the square of the distance from the centre of attraction, (the entire mass of the planet may be imagined as concentrated at the centre).

But the distance by itself can not be the determining factor, for on the equator of Jupiter, whose radius is eleven times that of our planet, the acceleration is 24.73 metres/sec./sec.; on the surface of the sun, whose radius is more than 107 times that of the earth, it is even 272.67 metres/sec./sec. Gravity therefore depends both on the mass of the body which attracts and of that which is attracted. If we let m_1 be the mass of one body and m_2 that of the other, and if the distance between them be r, the following formula holds for the attraction between them: $K = m_1 m_2 / r^2$. Gravity is therefore directly proportional to the masses of the two bodies and inversely proportional to the square of their distance.

Since the weight is nothing else but the downwards pressure due to gravity it appears from the formula quite clearly that the weight of a body must be proportional to its mass (m_2). But why does the mass of the body not alter the acceleration due to gravity? Because the general law holds: the acceleration which a certain force imparts to a body is inversely proportional to the mass of that body (m_2). Mathematically: $b = K/m_2 = m_1/r^2$. Since now the mass of a falling body (m_2) cancels out, the acceleration (b) must be independent of it.

In this way the action of weight and acceleration on free fall is finally elucidated. Both are caused by gravity which can be calculated by the formula $K = m_1 m_2/r^2$. This formula, however, conveys to us the innermost secret of the world of matter, in fact of all the world of space.

Gravity is the magic action of substance. Every body, since it contains substance, attracts all other bodies. This can be proved even of small objects (such as two globes of iron) on the surface of the earth. Outside in the universe, however, the revolution of the moon round the earth, that of the planets round the sun, and the motion of all stars, are based on the mutual attraction of bodies, *i.e.*, their innermost character, the substance. Things attract one another not as spatially separated bodies, but as substance. For even between non-separated bodies, between those which touch each other intimately, this attraction continues. Only because stones are always attracted by the earth, upon which they lie, do they exert a pressure on it. They strive not only towards it but into it. Matter tends towards matter, to unite with it. The unity of the material, of the substance, is the secret magnet which draws the stars towards one another.

Space is indifferent, it causes neither attraction nor repulsion; from it no motion can result. For it allows things to exist outside and next to one another, gives them mere ordered arrangement, and would like to convert the whole world into a resting, but clearly and strictly-built crystal. Motion is derived from substance. Its members, the different types of matter, are divided from one another twice; firstly by their own division into elements and secondly by space. Elements fly apart and are caught again by structures. The difference between elements and the fact of equivalent weights are the cause of the unceasing motion within the world of matter, and the isolation in space is the lever for the motion of stars.

Space is built up by points and everything that appears in it must be divided and must be arranged in a structure. The discrete points of a crystal, like those of the universe which we name stars and nebulæ, are formed by it. It divides matter, it divides masses and spreads substance into the universe. It holds things imprisoned in separation. The mother of things, however, is substance. It gives them their nature and their being. It is their unity and in substance alone they become one. It counteracts space, it dissolves the imprisonment. Like a mother who calls her children home, substance tends to collect and unite all matter. Element searches for element, star for star. Eternally seeking, eternally attracting, the planets revolve round the sun and the sun round a distant centre. Space alone does not allow them to unite. The universe is preserved in a marvellous equilibrium between the tendencies of space and substance.

In physics the gravitational force is treated in the same way as any other "force". The stone which on falling freely under the action of gravity carries out a uniformly accelerated motion, would, if gravity were counterbalanced, carry out the same acceleration under the action of any other constant force of equal magnitude. In the electricity plant water as a source of energy, rushing down under its own weight, serves no other purpose than could the combustion of coal or oil. The final issue is the same light and the same force to drive machines. If one could give gravity any desired direction it would move trams and trains just as do steam or electricity. In short, the mechanical action of gravity is fundamentally the same as any other form of energy. But are their characters the same? Is gravity itself an energy similar to the others?

The law of the "conservation of energy" has been put forward. It states that in order to gain energy one must sacrifice an equivalent amount of energy in a different form. If energy disappears in some form or other the same amount must appear or be present potentially in a different form. In order to produce electricity one must burn coal for example. Twice the amount of coal produces twice the amount of electricity. Once the coal has been used up, the electrical current ceases, and all trams are brought to a standstill. The same applies to production of steam for railway engines. With a certain amount of coal at one's disposal one can calculate a corresponding amount of useful work. Admittedly it is possible to store up electricity (in accumulators) and when the coal is used up we have the energy at our disposal in another form. But as soon as we cause useful work to be done the electricity is necessarily used up and the store of coal disappears. This work can be achieved only by the expenditure of energy. However great the store, it will finally be exhausted with use. The enormous reserves of coal on this earth will one day be exhausted if they are used to the same extent as they have been up to now.

The remarkable fact is that this use of energy and the diminution of the store through the work done does not take place in the case of gravity. Or is it that the attraction of the earth decreases perhaps when meteors fall into it, since they are drawn towards earth by the action of gravity with such enormous velocity? And if ever the moon were drawn nearer and nearer towards the earth and were one day forced down upon the earth (a fate which many moons have already experienced) would gravity suffer? Disregarding the mass of the moon, would we find the same attraction as before? In fact does the earth not always move the moon round it? And is that not work? If the attraction suddenly stopped, the moon would instantly fly away tangentially to its course into space until it would be forced into an elliptical course round another planet or another star. Does not the earth at every second draw towards it the moon, the sun, and all the planets. (Fig. 61, the planet would, if left to itself, fly away from P_1 in the direction T_1 and from P_2 in the direction T_2. By describing the arc P_1P_2 in its actual course it approaches the sun by the amount $P'P_2$. In the case of the earth the approach to the sun amounts to about three millimetres per second). Is this not a type of work like any other? And yet gravity exists throughout thousands of years, millions of years, and does work, never exhausted and never diminished. It acts without being used up. It would remain the same if only half the number of planets were dependent on the sun and it would remain equally unaltered if several others were attached to it. We have therefore, in the case of attraction of stars a force which acts without being used up, which does work without being diminished and which is of a definite, finite size and yet inexhaustible. Can this be a type of energy in the usual sense? Can gravity have a parallel?

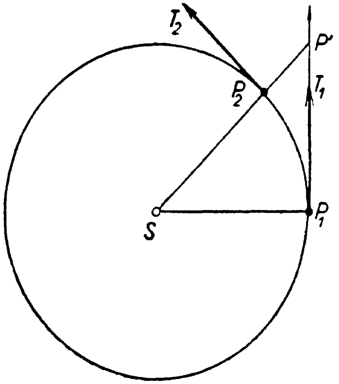

Fig. 61. Motion of a planet round the sun.

Admittedly it can be argued that static electricity, too, behaves in a similar way to gravity. Let us assume that there was no such thing as attraction between masses and that we could charge sun and earth electrically in such a way that they would attract each other with the same force as they actually do by virtue of gravitation. In that case the earth would revolve round the sun in the same way as it does to-day without the electrical charge ever being used up or diminished. But do the facts for this reason become less puzzling? And can we be satisfied with the explanation of the physicist that the state of energy of a complete system is not changed by internal motion? The fact that this state of energy does not change and that the motion continues eternally in the same way, is the puzzling factor in both cases. There is a further and important difference. A body may or may not be electrically charged. Gravity, however, is possessed by it *a priori* and it can never lose it as long as it exists. This means that in the universe the inexplicable is happening all the time, conditions which we are not able to imitate even by experiment with electrical changes.

What are heat, electricity and magnetism? They occur with bodies but they are nothing but states of these bodies. A body may be charged or uncharged with electricity, it may be warm or cold, magnetic or non-magnetic. The state of electrification, magnetization or temperature may be strong or weak, it may be constant or changing, it may last for a long time or it may pass quickly. Some bodies are good conductors of electricity or heat, or they may be bad ones. Iron loses magnetism quickly whilst steel retains it. How does this compare with gravity? Every body possesses its corresponding "mass" (more correctly, its material) and it can never lose it or increase it; this is always constant and always present. There is no gravity without bodies, but also no bodies without gravity. It can be neither induced nor conducted away, neither added nor subtracted. Gravity is not a state of the body, but belongs necessarily to it; it is only an aspect of its nature, the indicator of its substance. There is no body which does not owe its origin to substance, no body which does not contain substance, and for that reason no body which does not try to regain unity. And therefore there is no body which does not attract all other matter and which is not attracted by all other bodies. The spatial appearance is one aspect of the body, gravity, more strictly speaking the substance which is hidden in it, is the other. The bodily appearance changes and is subject to all sorts of conditions, gravity is rooted in a unity and therefore remains the same through all conditions and changes. Whether it is warm or cold, charged electrically or not, magnetic or non-magnetic, the body has the same weight, exercises the same attraction, and is also attracted in the same way by all other bodies. Gravity alone is part of its essence, everything else is merely part of its appearance. Gravity is as everlasting as the substance, it is never used up because its nature, its non-spatial aspect, is the indication of being. All being would have to perish if gravity were to disappear.

The question arises, can pure gravity be grasped or expressed in any other way but as a mere number? The expression m_1m_2/r^2 which determines gravity is not a constant, but an ever-changing entity whose value is dependent on two masses and their distance apart. The distance (r) actually implies only a spatial relation and has nothing to do with the substance which we wish to explore. That distance does not bring us any nearer or further from the concept of substance. The two masses on the other hand are two veils which both take the concept further away from us.

If gravity, as was shown, is a direct expression of that eternal uniformity of substance, then it must be identical with itself always and everywhere; mathematically speaking it must appear as a universal constant. Only this unchangeable, universal number could unveil the deepest secret of external being as far as this is possible in reality. But how can we find this number, this one constant of the spatial universe?

The following discussion may pave the way. The body is a spatial, material structure based on substance. In order to express the nature of bodies it must be divided indefinitely, *i.e.*, divided into points. These points are the elements of all bodies. They are beyond all real structure, they are at the boundary where the unity of substance begins to form the universe. As points they can contain neither space nor matter. But the point is the root of bodies. Every body, however small, is made up of an infinite number of points (as is every part of a line). In spite of this a body twice the size of another body contains twice as many points, a body half that size contains half the number of points. This is that hidden region where the inexplicable becomes mathematically explicable, where the unity becomes a number.

If—and any other assumption is unthinkable—the substance underlies these conceptions as unity, then at every point in the realm of bodies, untouched by all physical and chemical properties (which can not exist at all in a point) substance must necessarily appear. Twice the size of a body must correspond to twice the quantity of substance and half the size to half the quantity. This is the actual concept of mass and the origin of weight.

"Mass" is thus that part of a body which can be grasped as a homogeneous system of an infinite number of points, and in these points alone the properties of the substance emerge. The sum of the action of these points we denote as gravity. A body of twice the mass produces twice the force. This explains why gravity must be proportional to the mass. Only by the fact that it is originated by points can gravity be treated mathematically. Here lies also the final explanation of weight, which goes hand in hand with mass. Since for every point on the earth's surface one mass (the mass of the planet) and the distance r (radius of the earth) are constant entities, the weight (the gravity) changes only with the second mass (the mass of the body to be weighed). For the same reason the acceleration g due to gravity must be constant. In that case every point in the falling body is attracted by the same force and is at the same distance from the earth, so that all points must always fall with the same acceleration, a piece of rock in the same way as a particle of dust.

In the formula $K = m_1 m_2 / r^2$ the sum of all the forces of gravity emerging from the body is taken as one entity depending on three variables. We do not deal with substances as single points. If we desired to recognize the true aspect of substance, or at least to recognize the forces produced by it, we would have to express the force of attraction between single points as a number. Only that one number would be a universal constant; the substance is identical with itself at all points in bodies of the universe, and the lines of force merging from every point must be the same for every point in the universe. This constant, which is necessarily infinitely small and which is nevertheless a definite number would be the only one in which the substance would appear as unity so that we would unveil that which will remain eternally veiled. The last and final universal constant of the universe will never be determined; for infinity divided by infinity gives an indefinite number; in other words, the inexpressible can now never be expressed. It was just this constant, however, which was to unveil to us that unity which we assumed and which we can never discover, it was the hope, the actual aim of our discussion. Since that last, ideal aim can never be reached we must be contented with some realistic view-point.

Physics may be our guide in this. If gravity is to be expressed on the centimetre-gramme-second system, we must multiply the faction m_1m_2/r^2 by a definite number (G) so that the strict formula is $K = G\,m_1m_2/r^2$. If m_1, m_2 and r are equated to unity the value of G becomes 6.66×10^{-8}. This number, the *gravitational constant* is an integral of the constant we have discussed above and allows us to suspect the presence of substance behind the veil of mass and space rather than allowing us to recognize them directly. But it does convey to us the final, tangible recognition of the universal uniformity, the deepest knowledge which we can gain. In a roundabout way it brings us near our original aim. For the constant G discloses the substance, too, not entirely unveiled, but as a unity and final basis of the universe.

The gravitational constant does not give us anything fundamental concerning bodies or matter but only concerning the internal unity due to the intangible substance. The value of the gravitational constant is by no means definite (perhaps it should be 6.67×10^{-8}, or even 6.68×10^{-8}) and it may be questioned whether it can ever be determined exactly. It is certain, however, that this constant, whether or not it can ever be known accurately, does apply in the universe, and is anchored in the substance, and determines the whole of the outer being. The gravitational constant is a fundamental fact of the first order. All the world depends on the gravitational constant G; with its value all the universe would have to change.

If we imagine a world in which the gravitational constant were, for example, four times or sixteen times as large, then the earth would make a complete circuit of the sun in a half or quarter of a year; all planets, moons and comets would revolve round suns and stars with twice or four times the speed. Sun, planets, clusters of stars and all nebulæ would rotate faster in the same proportion. Our system of time measurement would no longer apply. There would be no second, no minute, no hour as we know them, years and days would be shorter, clocks would tick faster. Time itself would accelerate its rhythm and would take everything with it in storm. Our sun, stars and systems of stars would be correspondingly larger, every star would be more dense, radiation would be more intense, and the heat greater. Our planet would be surrounded by a denser atmosphere, every body would be of greater weight; stones would fall towards earth more rapidly and streams would flow more swiftly towards the sea. Plants and animals would have firmer bodies and a more robust build.

Our bones and muscles would be stronger and our gait more deliberate, for our will would be more fiery and violent, our soul would be more irritable, but our characters more manly and stricter, our beliefs more heroic, and fate more tragic.

On the other hand, had the gravitational constant a considerably smaller value, G/16 or G/25, then planets and comets, suns and stars, would rotate more slowly and revolve round their axes only in four or five times the time. A day would last four or five times as long, spring alone would last a year. Sun and stars would be smaller, the earth would receive less light and heat. All bodies would have smaller weight and would fall more slowly towards the ground. To play with five balls in the air at the same time would no longer by a skilful feat but it would be child's play. Mountain streams would have lost their wildness and would flow lazily to the sea. Thin, transparent air would surround our planet. Plants, animals and men would have more delicate shapes, they would be thinner and more flexible in growth. Men would hurry along with ease. Fast motor cars would move more through the air than on the ground, in fact there might not be such vehicles at all; for the strength of machines would be entirely unpopular and far too crude for our refined sensibility. Probably electricity would not have been discovered so soon, nor would it have been used so much, and the wireless would never have been introduced; the cinema would appear to the simple placid people only as madness or the work of the devil, even a steamship would hardly be tolerated and we would give ourselves pleasure with wind and sails.

Everywhere one would meet friendly natures, childlike attitudes and innocent manners. Fury, tyranny and wars would be unknown on earth, or at least despised and hated. For men would possess a natural religion, and would believe in mild gods, would neglect science, and would take a pride in music and dancing. The stars would shine on a less sinful world and the sun would bend its rays upon a happier generation.

It is questionable whether if gravity were changed the earth would remain in its present position, in fact if it would be present at all. There would probably be quite different planets. Even the sun might not be found among the millions of stars, and our system of stars might not be recognizable. So we must finally assume that men would never have seen the light of day at all, mankind whom alone we know and whom we have pleasure in regarding as the crown and the final aim of creation.

Another gravitational constant would have created an entirely different universe. Only the crystal would be the same, the crystal as it actually is. There would be the same crystal systems and classes of symmetry, the same lattices and the same habits. But the surroundings of the crystal would have altered, even its source of nourishment, the mother liquor. The single crystal would thus show a different habit in many cases but the one habit it would show would necessarily be a possible one even in our present world. As far as a crystal is a pure crystal, the gravitational constant which rules all can not affect it. For, whatever value it may have, the crystal has superseded the substance and has undone its magic action, gravity.

APPENDIX

LIGHT

AS A PHYSICAL PHENOMENON,
AS A MODE OF THE ORGANIC, AND AS A CRYSTAL

Introduction

THE spatial world of bodies is the direct representation of the inorganic which rests therein and finds its completion as the crystal. The organic and the spiritual on the other hand do not originate from this world; they are mere strangers or guests within it, which at their death loose the ties of bodies and leave the organism behind as a cadaver. Together with life the body loses its nature and its senses. As it decays it falls back entirely into the inorganic. Only plants and animals can decay, but not the crystal. We can break the crystal, grind it, or dissolve it, but we can never kill it. For the principles, which build it up, substance and space, are present even in the atom. How could they disappear from their own sphere, the spatial world of bodies, since they are their own creators, their own self? Creation would have to proceed backwards and the universe would have to disappear into nothingness if the crystal were to lose its character. The crystal is in fact identical with the spatial world of bodies, the means and perfection at the same time. This implies that the crystal can not die as long as this world exists, its body can not decay, but can only wither.

The outside world is not one single plane of being, but a real world (the inorganic) into which two other strange spheres have broken (the organic and the spiritual). And now a new character flashes through the universe, like an intangible glow: the light.

CHAPTER FOURTEEN

LIGHT AS A PHYSICAL PHENOMENON

IN the spatial world of bodies light is a very puzzling phenomenon. It must remain a puzzle as long as one attempts to explain it from the structure of the world. The conception of the nature of light therefore is always indefinite and will remain so. The theory of emission regarded it as a fine type of matter originating from a glowing body; the electro-magnetic theory of light on the other hand regards it merely as oscillations of the ether. Modern physics, based on the theory of relativity, attributes mass to the light, as to any other type of radiation, and to all other types of energy. Light does indeed exercise a certain pressure, similar to bodies, which can be measured and which has been observed at total eclipses of the sun, as predicted by Einstein: that is to say light rays are subject to the mass attraction of the sun, and to gravitation in general. According to this one would imagine that light is something material, for only matter causes bodies to attract bodies.

Yet, there is a fundamental difference. According to the above-mentioned theory every body at rest possesses a certain mass, but as soon as it moves its mass increases. The greater its velocity the greater its total mass. On approaching the speed of light (the greatest velocity possible in the world of space) the mass increases rapidly and at the moment at which the speed of light would be reached every body, however large or small, would attain an infinite mass.

We must now ask: why does light not possess an infinite mass, since it progresses with the velocity of light, but why has it in actuality an almost negligibly small mass? (The pressure of light is extremely minute and it is difficult to demonstrate). And, theoretically speaking, what would be the mass of light at rest if its total mass at the highest velocity is so minute? It must be zero and this means that it does not possess any mass at rest. And it is just this mass which a body possesses at rest to which it owes its material character, whilst the increase of mass is only due to its speed. From this it follows necessarily that light, even when the relativity theory is assumed, can not possess a material character. And what is not material can not have a body. Why it is that something that is not a body can exert a pressure, is left to physics to explain, for the question arises in the case of every type of energy.

In any case, we may say that light is non-material, and incorporeal and does not behave like a body. Liquids and even gases, can be caught and kept in receptacles. This is not so in the case of light. Where there is a body there can be no other; but where there is a body there may without diffinity be light. Light can pass through glass or a crystal and glowing bodies glow at all points internally as well as on the surface.

"Visible" light does not occur in the world of bodies as a determining factor, but is merely tolerated; it is subordinated to the structure of bodies (the crystal) according to certain physical laws without taking part in their structure and without endangering or changing it. Indeed, it ignores the peculiarities of the crystal structure as it passes unhesitatingly through it. For light does not recognize either the points or the planes of the lattice, but reveals only the general symmetry relationships. The sun's rays therefore go through a cubic crystal, whose axes are all equivalent, with the same velocity in all directions, whilst in a uniaxial (tetragonal or hexagonal) crystal it can travel with two different velocities corresponding to the two differing axes.

However clear and obvious this relationship may seem it is by no means self-evident, but it can be understood only from the nature of light. If mineralogists contend that cubic crystals would allow light waves, originating from the centre of the crystal for instance, to have the same conditions of travel in all directions, this would be strictly untrue. Certainly the three axes are equivalent, but the resistance which meets the light in the form of the atoms is by no means equal in the different directions. We may, for instance, consider the body-centred cubic lattice (Fig. 13). As a source of the light wave we may take the centre atom O_2: if we denote the length of the cube with a we would have along the face diagonals the continuous inter-atomic distances of $a\sqrt{2}$, whilst along the cube edges the distances would be a, and along the body diagonals $a\sqrt{3}$. Nevertheless, the ray of light does not travel with the same velocity only in these three directions but also in all intermediate directions. Admittedly, the lines with greatest distances between atoms would lie the closer together, so that the decreased resistance due to the wide separation of the atoms would be counterbalanced by the increased resistance due to the closeness of the lines. But what does this summation of resistances imply other than a complete disregard for the lattice points in the unity, the transition of the particular structure into a general form in which the atoms and their distances can no longer be recognized; in other words: the dissolving of the crystal structure in the structureless element of light? The regular crystal appears in the light not as structure with certain planes, lines, and points but as a formation of a general spatial form, namely that of a globe in which there are no isolated points.

From this it follows that light does not affect the perfection of a crystal as it travels through it for it does not fracture the lattice (as cleavage, percussion, and etch-figures do). Furthermore, it transcends in general the unity of shape; for it reflects in no way the present or possible faces of the outside shape. As far as the light is concerned the crystal is completely homogeneous and present only inasmuch as by its density it determines the velocity, which is different from the velocity in other media or through empty space; shape and structure, however, do not appear at all. Light thus travels through the cubic crystal as through any ordinary, transparent body, whether solid, liquid or gaseous.

The most characteristic property of light as a physical phenomenon which can be mathematically completely described is given by the laws of reflection, refraction and polarization.

If a ray of white light falls on a uniform surface of a transparent body, it is divided into two rays, one of which is reflected at the surface whilst the other penetrates into the body and is deviated from the original direction (Fig. 62). If a line is drawn perpendicular to the surface at the point where the light ray falls on the surface and if the angles which the incident, reflected and refracted rays make with the perpendicular are denoted by the angles of incidence, reflection and refraction (e, z, r) the following laws hold:

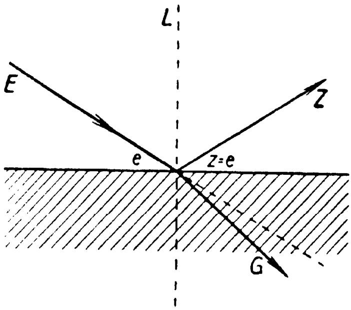

Fig. 62. Refraction and reflection.

1. The perpendicular and the three rays are in the same plane.
2. The angles of incidence and reflection are equal ($e = z$), whilst the angle of refraction is different and depends on the optical density of the refracting body. If the incident ray travels from the lighter to the denser medium it is refracted towards the perpendicular ($r > e$); vice versa, if it

travels from the denser medium to the lighter medium, it is refracted away from the perpendicular, ($r < e$).

To begin with we will follow the ideas of the physicist and we will regard light as a wave motion. The body, as far as the incident ray is concerned, has a twofold function: its surface is a wall which holds it back and at the same time it is a lattice into which it may penetrate. The fact that in spite of the transparency the incident light is retarded is shown by the fact that the refracted light shows a diminished velocity compared to the incident and reflected rays; in diamond the speed of light is actually halved. More correctly expressed: the assumption that the denser medium retards the refracted beam is sufficient to explain the bending of the light towards the perpendicular.

Since light is propagated in empty and homogeneous space as a spherical wave it travels at every point of that sphere in the direction of the radius. If we imagine the process to take place in a plane the sphere appears as a circle from whose mid-point the wave originated (Fig. 63). A small element of arc *AB* (drawn for the sake of clearness on far too large a scale) travels in the direction of the radius S. If it now falls on a bounding surface of denser material which is obliquely inclined to the direction of the ray, the end *A* of the arc which first falls to the surface is retarded as it enters the body whilst the other end of the arc is still travelling with undiminished velocity until at the point *B′* it also falls on the surface. In the time in which the other part has travelled the distance *BB′* the former will have travelled a shorter distance *AA′* in the denser medium. The arc which is formed in the denser medium and which now proceeds with uniform velocity is displaced from its original position and the ray direction *S′* compared to the original ray direction S is deflected through a certain angle towards the perpendicular *L.* The ray has been refracted and the wave proceeds as though it had originated from the point *O′*. If the arc is now decreased to infinitely small size then at every point of the circle the same refraction will take place when falling upon the surface. The same process can be imagined in three dimensions in space.

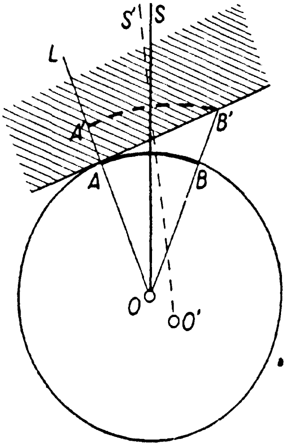

Fig. 63. Illustration of refraction.

Light can be understood by yet another method with the help of the body on which it falls. Light vibrates equally in all directions at right angles to the ray direction. If it falls on a body, however, and is reflected at the surface it will still vibrate perpendicular to the ray direction but not at all inclinations at right-angles to the ray, only in the direction which is parallel to the reflecting surface (Fig. 64). The light is said to have become "polarized". The same fate is experienced by the refracted ray (Fig. 65). In this way reflected and refracted rays are polarized at right angles to each other.

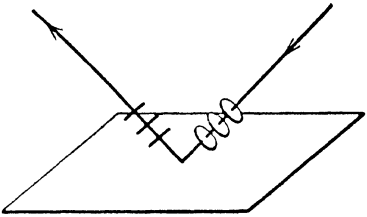

Fig. 64. Polarization of the reflected ray.

How does the light behave when it falls on a crystal, which presents a definite, unchangeable structure? The reflected ray which never enters the crystal and is therefore not affected by the structure is reflected in the same way as from a non-crystalline body, *e.g.*, glass. The penetrating, refracted beam shows the relationships of the crystal in the following ways:

In the cubic crystal, whose axes are equivalent, light is refracted and polarized just as in the case of glass or any amorphous mineral.

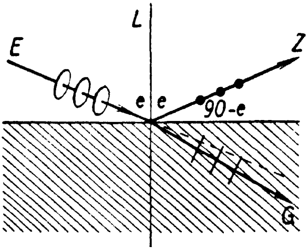

Fig. 65. Polarization of reflected and refracted rays.

In uniaxial crystals this applies only to a ray which enters the crystal along the direction of the vertical axis. In any other direction double refraction occurs. This is clearly shown by the double refraction of calcite (Iceland Spar). If light enters a cleavage face it is divided into two other rays which travel through the plate at different angles. If the plate is rotated in its own plane one of these refracted rays maintains its direction whilst the other changes its direction on rotation. The first ray, which obeys the usual laws of refraction, is denoted as the "ordinary", the second as the "extraordinary" ray. The more inclined the incident ray is with respect to the principal axis of the rhombohedron, the larger is the angle between the refracted rays. Its maximum is reached when the ray direction is perpendicular to the principal axis. As can be demonstrated with a nicol prism the two refracted rays are polarized at right angles to one another (Fig. 66. On the left the ordinary ray is shown, and on the right the extraordinary in each four different positions).

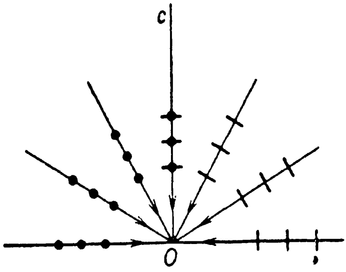

Fig. 66. Ordinary and extraordinary rays.

Orthorhombic, monoclinic and triclinic crystals also show double refraction, but in this case the angle of refraction of both rays changing on rotating the crystal, *i.e.*, both rays are extraordinary. They are polarized and again their planes of vibration are perpendicular to one another.

The effect of the spatial relationships of bodies upon light, enables us to understand the phenomena of reflection and refraction. Even double refraction can be explained without further assumptions about the nature of light. It must be mentioned, however, that such explanations do not concern the essence of light and can therefore command a value as illustration only. In actual fact the spatial properties and dimensions as well as refraction, polarization, velocity, frequency and wavelength are the only features of light which exact science can determine. All special assumptions about the nature of light on the other hand are *a priori* problematical. The electro-magnetic explanation deserves preference as it denies material character to the light; about the real essence of the light it can, however, say very little, as also about electricity, magnetism, etc.

As long as one speaks of vibrations one is forced to assume that there is an underlying *something* that does vibrate. Careful assumptions about "fields" do not help in any way, because the question remains unanswered as to what does vibrate or determine the condition of the field. If a modern scientist says:* "By vibration directions we should not imagine the direction of something material which is moving, but merely the direction of a wave radiation connected with electric force; together with the electric force there exists a magnetic one at right angles to it . . .", the difficulty is by no means removed, for what is wave radiation in which the "electric force" takes part? Whatever view we may take there must be something which is progressing in wave form, something which radiates and appears in electric and magnetic conditions. A mere mathematical wave is never an object for physics. But it is the strange, problematical, if not tragic aspect of this science that behind all its explanations there must be *something* which is the carrier of these conditions, which penetrates into that science from a strange world, and which can never be grasped by the means at the disposal of that science.

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*Sommerfeld, "Atombau und Spektrallinien", p. 28.

The purpose of these discussions is to go beyond the limits of mathematical understanding and to make in a modest way these problems plausible within everyday conceptions. It would in fact go beyond the limits of this book to attempt to determine the essence of light, but the trial of understanding how the properties of light are connected with its essence must be faced.

If light is not material nor the vibration of something material it can not belong to the world of bodies, nor to space at all. The world of bodies alone can be spatial. If light still shows spatial properties (rectilinear propagation, refraction, plane of vibration, wavelength, etc.) these properties can not be the expressions of light itself but merely impressions from outside. Things which by nature are not spatial can accept spatial aspects but can not determine them.

In this way light as such can not appear in the world of space. The experience of physics is only in appearance contradictory to this statement. In physical investigation light in itself can not be grasped, but merely in its connection with bodies. All perceived light must have been refracted or reflected by bodies and in that way endowed with the structure of bodies. In addition the fact emerges that the physicist must always consider a small ray of light selected from the vast ocean of light beams. From the property of a small ray he attempts to derive laws concerning all light. A single ray is present in real light to no greater extent than the mathematical axes in a crystal. For light originates in a structureless form from its source, and passes into limitless space. Only if space were unlimited, *i.e.*, if it were not space at all in the physical sense of the word, would light remain within its own sphere and be pure and non-spatial. In the ray is embodied already the straight line, the fundamental aspect of spatial dimensions, the world of bodies. What a ray can show us is no longer the property of pure light but a projection into the spatial. The laws which we have described are obeyed, but they are only a dim representation of the truth. Even the assumption that light is propagated in the form of spherical waves involves spatial considerations in the non-spatial and measures light in a way which is foreign to its essence. If we disregard vibrations in the ether we can not simply denote points of equal condition by a spherical area. In this way one has merely deprived the contradiction of its sense, but not abolished it; all space, even mathematical, includes the conception of limitation, but limitation can only be attributed to the world of bodies.

Admittedly experiment seems to justify all physical assumptions. 'The Interference spectra are undoubted facts and they are in complete agreement with the theory of spherical waves. But interference can only be obtained by limiting the light spatially (by some lattice) and if one forces it to bow down to the spatial, it is no wonder then that interference can be measured by spatial means and that it can be so explained. Without bodies there can be no interference of light, but in the sphere of light there can be no bodies. What optics describes is not a property of light but only its imagine in the spatial world. Superimposed, interfering, crossing and enhancing spherical waves already imply a type of structure which, though not taken from solid bodies, is derived from fluids. But light is no more a fluid than a solid body, it is not a body at all.

Polarization involves only a further stage in the estrangement, and refers to a two-dimensional plane instead of to a three-dimensional sphere. Light on the crystal face must have been converted into a type of crystal. Admittedly it has not solidified; for polarized rays are still influenced by crystal planes and may be even de-polarized. But this does not happen to the light itself without the influence of bodies.

Light is by its nature absolutely uniform and indivisible. Since it has no structure it does not exhibit any possibility of division. It is divided only by the bodies on which it falls. The purest element of space is the straight line, and only the plane boundary of a body can divide light. Only if the surface is made up of elements of planes can they reflect and divide light, and the manifold and changing divisions result in "scattered" light. It is again the spatial which forces a spatial property on light, that of division. Light itself did not cause division or polarization but rather it was hidden behind these phenomena.

Light as such is all-pervading, it has no fractures and no empty cavities, and it possesses no dimensions, neither fixed nor changing. It merely touches bodies. Towards bodies it is not active but only passive. When travelling through a body it is changed by the structure, but the structure is not changed by the light. It is a pure flow and yields itself to the crystal as if to an active will.

CHAPTER FIFTEEN

LIGHT AS THE MODE OF THE ORGANIC

ALL that we can measure, calculate or determine in light, the laws of all optics, are in reality not concerned with light, but only with its impressions which it has received from bodies and in which the shapes of space are reflected. What we see is never light itself but only its reflections from bodies. Not only our own image in the mirror but all images, real and imaginary, which are produced by lenses, in fact every ray that strikes our eye, all the abundance of light which shines on the world on a clear summer's day, which fills the air and which oozes forth from every particle, all this is nothing but reflections of the spatial, images of bodies. Only in the world of bodies does the light awake as we know it, it is visible only in bodies. Light as such can neither be seen nor experienced. All we see and feel as warmth, all we regard as radiation due to light is still only the surface of its nature. Apparently it exists, in fact it is always present, lighting up the world of bodies, and still it never shows its own aspect, and its character is hidden to us as an eternal secret. Even if it wished to unveil itself it could not appear in its own form as long as we remain in the world of space. Light has no spatial shape and it does not exist in the world we know. By that we mean nothing mystical but the mere facts which everyone can understand and must understand if he is to think clearly about these problems.

Light is no more mystical than normal bodies, but bodies belong to space and therefore exist directly in their own shape, whilst light can only appear in that sphere as a reflection, as a *fata morgana.* It can be proved directly that light itself can not appear in any way. The rays of the sun diverge in all directions towards infinity and flow through space at all points which are at the same distance from the sun as the earth itself, with the same force as that with which they strike our planet. Even so light awakes only in our atmosphere and is exhibited only on our bodies. The more matter loses itself towards the outside of the atmosphere where the smallest particles disappear, the more does light disappear. Where finally our atmosphere ends, and empty space begins and light is completely lost. All space between the outer layers of our planet and the edge of the sun is filled with stronger light than is present on the earth, but it is still eternally dark. Every body of the universe, however, which happens to come into the path, however small a fragment of a destroyed star it may be, glows and wakes the rays which would otherwise have remained hidden. Every body glows either by itself or by rays which have originated in others, but the space through which the rays penetrate is absolutely dark; light can not appear in it. It is to the darkness of space that we owe the wonderful blue of our sky.

Not only can light not be seen in space, but it does not exist in it in any way. Just as visibility, so every other property of light depends on bodies; warmth electro-magnetic radiation, light pressure, energy, or chemical action, can flare up only on bodies. In empty space, therefore, every expression, every action, and every sign of the presence of light has been denied. What remains then? Vibrations? But what can vibrate in empty space? Fields? What can change a field if it be not matter or energy, which are both absent? What is there left of light? Nothing, light itself has become nothingness. Or is it velocity? But what sense can there be in talking about velocity of nothing? There is no escape. Light does not exist in empty space. It is present only as a possibility, it can flare up at any moment if a body becomes its torch. Possibility, however, is not reality. We can thus take it literally that light does not exist in empty space, that it has no real existence.

But is not all this the case for every force and every radiation? What is the anchor of gravity? Only the body, and between bodies there is nothingness. For every body that enters the "field" is grasped by gravity as though lit up by a ray. Light and gravity as well as all types of radiation are true sisters which are manifest on bodies but disappear in space. In the physical world they are only guests, true "Mädchen aus der Fremde". If science deals with them in the same way as with bodies as measurable quantities, *i.e.*, as familiar entities, it is not the fault of the former. They have never unveiled their essence and have never tried to hide their strangeness. To nothing more than to physics in its relation to intangible forms of being do Goethe's words apply: "Am farbigen Abglanz haben wir das

Leben". In relation to the essence of light the whole of optics is a mere simile.

The question now arises, why can non-spatial things assume spatial properties? The fact that light is rectilinearly propagated, that incident and reflected rays lie in a plane, that polarized light has a vibration plane, are simply facts which can not be denied. Indeed, it must even be assumed that in empty space, where it does not have any action, light retains its velocity of propagation, which can be determined when it falls on a body. Fundamentally, this special case is not different from the general behaviour of light. The fact that in places where it is not present it shows a definite velocity is no more wonderful than that it is reflected, refracted and polarized by bodies. In all these cases it shows spatial characteristics, although it is not spatial itself, but all the images, radiation, and forms of energy which are apparent to us in space and which can be explained geometrically, and by numbers, are not even phenomena, but only the actions of light. To attempt to ascribe physical properties to it for that reason would be as absurd as an attempt to measure a thought in centimetres or in grammes. In the same way that a thought without being visible or measurable can still have an action in the world, even to a great extent, so light can also reflect in a world to which it does not itself belong.

Admittedly there is a difference. Thoughts are known to us from the inside, *i.e.*, from their own, and from the outside in a foreign sphere; but in the case of light we can only have the reflection of a strange realm. Light exists in the degree of the inorganic; it is neither alive nor is it produced by life. But it is manifested from a second, deeper layer of permanent substance, and does not obey space as substance does in bodies, but traverses the universe as a unity in the same way as the organic. We can say shortly: *light is the mode of being of the organic in the degree of the inorganic.* We would have to be pure plants to understand light in the same way as we understand our thoughts or ideas. Our organism is subject to the spiritual, and does not understand or have need of light to any greater extent than the plant, and the purely organic in us lies outside our consciousness. As far as our body is merely organic it can flourish or die, but can never reach consciousness. Even pain as we know it, *i.e.*, as a conscious feeling, has already reached the spiritual and is therefore foreign to the organic and to the plant.

Admittedly light is neither in character nor origin actually organic but it does preserve the mode of the organic to an even greater extent than the plant, in which the organism or even the organic seems interrupted by the plant body, whilst the light never becomes really corporeal, but is only reflected by bodies. It is at a lower degree of being than the plant.

But if light has retained the pure mode of the organic in its flow and unity, it becomes understandable that it should be subject to gravitation. For gravity is nothing else than the action of the innermost unity, the substance, which remains so even in the divisibility of the world of space. Light is not attracted by bodies, but by substance which lies in them.

The relationship of light to the organic is revealed clearly in its relations to the plant. All life has need of light, it is refreshed by it and recovers from estrangement in space. All living things have bodies and are subject to the pressure of gravity and the division which it entails in space. The organic as such is a pure continuum, but the body is divided up into individuals, which the plant can not reform to a unity. Plants would tend to melt their bodies if they only could, but only at the time of flowering, the plant wedding, is its longing fulfilled. The body melts away into odour and colour. The colour is the life of the plants as it breaks forth from the bodies in the longing for the infinite and for the deprived unity. Colour for the plant is what language is to us, the glow of the blossom is its expression of love.

Apart from the breaking forth into blossom the plant must be satisfied with a green colour which again it owes to light, for with the aid of light chlorophyll is formed. Light is the first creator of life, the consoler of plants, the maintainer of the organic in the world of space; without light, no life!

CHAPTER SIXTEEN

LIGHT AS A CRYSTAL

IF light is passed through a prism made of glass or any other transparent substance, it is not only refracted as a whole, but is split up into all the colours of the rainbow. The colours appear as an absolute continuum from the red, which is least, to the violet, which is most deviated with respect to the direction of the incident ray. Physics has assumed since the time of Newton that in white light all colours are contained, and are merely separated by the prism. Since, however, physics itself regards light as a wave motion or wave radiation, it is at least difficult to imagine how that infinite number of different waves—every line in the spectrum, however narrow, corresponds to its own wavelength—can be contained in one light beam. In actual fact many well-known thinkers have definitely opposed this conception (amongst them in particular Goethe, whose ideas were taken up by Schopenhauer). In view of the successes of exact, *i.e.*, mathematical modes of thought, all these objections had to disappear in the course of time, and to-day the explanation of the spectrum as a division of light into different wavelengths has attained the significance of a dogma.

In reality the band of colours which emerges from this apparently homogeneous beam is only a small part of the total array of wavelengths. The spectrum continues indefinitely on both sides, though not perceptible to the eye; both beyond the red into the infra-red, and beyond the violet into the ultra-violet radiation. These invisible rays can be proved to exist by their effects—the infra-red by their heat properties and the ultra-violet by their chemical action.

A wavelength of about 800 $\mu\mu$ corresponds to the red edge of the spectrum, and to the outermost violet corresponds a wavelength of about 400 $\mu\mu$. That is to say, the visible spectrum shows at its extremities wavelengths which are in the ratio of 1 : 2; it may therefore be said that it includes an optic "octave". In the ultra-red, wavelengths have been measured up to a value of 0.343 mm., and in the ultra-violet down to a value of 13.6 $\mu\mu$. Whilst the visible spectrum contains only one octave, the infra-red contains eight and the ultra-violet five octaves, so that we perceive as colour only a fourteenth part of the total spectrum which actually emerges from the light; more accurately, we should say that these are the limits which so far have been demonstrated and measured. For there is no reason why we should assume that wavelengths do not exist beyond these limits. The invisible rays must be present in the white light in the same way as the visible ones.

We must now ask how could that infinite number of rays have been present in the one beam? Can we imagine at all that they were really present one beside the other in every ray, which in that way would be the sum of all of them? Is white light really made up of colour, thermal, and chemically-acting rays, which owing to their varying refraction are divided when passing through the prism into at least fourteen octaves?

If we wanted to understand white light physically, similarly to the single rays of the spectrum, we would have to imagine the undivided ray itself as a single wave of certain wavelength which would correspond to a mean of all single rays present in it.

This wave would of course have a different shape from those of the spectral colours since the intensities (amplitudes) of all the separate single rays must be somehow or other preserved in the final form. The coloured rays would then not be divided into a variety but would form a unity in the sun's rays. Regarded in that way white light would not be made up of a single ray but would energe as a unity from glowing bodies. Naturally it would always remain a puzzle why that total wave could split up in the prism into an infinite number of well-defined single rays. But this phenomenon is by no means more mysterious than the facts of reflection, refraction and polarization.

It is just the unity and continuity which is the deepest and most characteristic property of light. We can of course mention the line- and band-spectra which are given out by glowing gases; the former are explained by intra-atomic, the latter by molecular, motions. But it is that glow of gases to be considered as light, in the same sense as that due to glowing solid or liquid substances, *e.g.*, the radiation of the sun? Surely, it is white light which appears as a complete continuity, whilst the latter spectra are made up of discrete lines. Even if these lines appear in thousands and even if several bands are superimposed on one another can they ever become continuous? Even if, as in the case of hydrogen for example, an almost continuous spectrum can be achieved, the question still remains whether it corresponds with the spectrum of the sun or with that of glowing bodies, *i.e.*, whether it possesses the continuation in the infra-red and ultra-violet in the same way. Only when all wavelengths show the same continuity and intensity can we assume a continuous spectrum, and then only can we regard the radiation from which the spectrum has been derived as light in the true sense of the word.

Nothing justifies the assumption that the single spectrum lines or any definite part of the continuous spectrum has the same physical essence as the undivided light. In fact, every contact with bodies influences the physical behaviour of light (*e.g.*, polarization may be caused). Passage through the prism even divides up like a fan and on passing through the prism it must have experienced some changes which destroyed the identity of the original beam. At least, the following difference must be recognized: the spectral line is a part, a ray of white light is the whole. The whole and a part of it, however, can never be identical, just as one arm or foot is in no way similar to the total shape of the human body. A similar relationship to the human organism and its members really does exist in division of light. Light is the whole, just as the complete shape, every line of the spectrum is a part, as the single member. The sole difference is that we only have a limited number of members whilst the spectrum is made up of an infinite number of lines.

Regarding colours as entities, between which there exist all transitions of continuity, the simile still holds. Passing from one part of the human body to another there is at least at the surface no strict division and one part is joined continuously to the other. Since light actually does conform to the mode of the organic this similarity is by no means surprising but definitely plausible.

On the other hand light does not belong to the degree of the organic but to that of the inorganic and its anatomy is not completely the same as that of the human body. The visible part of the spectrum from the point of view of the colours retains the mode of the organic and the continuity of the spectrum as a rule falls into this category.

Only a comparatively small part of the spectrum, one single octave, appears as colour, whilst the other thirteen or more octaves reveal themselves by their characteristic actions on bodies; they warm these and change bodies chemically, or set them in motion; in short, they manifest themselves as *energy*. It must be emphasized at this stage that the infra-red rays have a continuous transition to electrical radiation. Infra-red rays have been measured up to a wavelength of 0.343 mm., but from the other side rays have been produced by electrical discharges down to a wavelength of 0.22 mm. That is to say, the rays of wavelength from 0.22 up to 0.343 mm. belong both to the spectrum and to electrical waves and it can scarcely be open to doubt that these rays are identical. In physics in any case they are regarded as "electromagnetic radiation" and are assumed to be equivalent if their wavelengths are identical. In this respect, that wave radiation from the largest to the smallest wavelengths is of the same nature, the electro-magnetic theory of light has recognized an important truth and has opened up with wide views an important unification. For all wave-radiations as far as they are physically conceivable have the same nature, namely that of electro-magnetic radiation, and the continuous spectrum shows no definite boundaries at either end. In the infra-red it extends into the region of electrical radiation. Is the idea not close at hand that it continues, though with decreasing intensity, indefinitely at both ends and that it really contains all radiation which we know, or rather which exists? If they have been proved to exist up to a wavelength of 0.343 mm. should not there also be present radiation of wavelengths exceeding metres or even kilometres? And why should there not radiate from the same light towards the other end wavelengths up to 136 Å (=13.6 μμ), or even shorter waves; why not even X-rays, which have been measured up to 13 A (= 13,000 X.U.)? Can it be explained in any other way than that all rays which can be generated by electrical discharge or by means of the X-ray tube are actually present in white light, although perhaps not proved at present, or in the most extreme parts never capable of proof? The longest waves which are known to wireless telegraphy measure about thirty kilometres or even more, the shortest known rays (γ rays) only 20 X.U. We must assume that even they are present in the spectrum to an infinitely small extent. The spectrum may have no limits at all but may continue indefinitely towards both ends. If we have already measured fourteen octaves it seems by no means impossible that the twenty-six octaves which make up the radiation so far known to us (Fig. 67) are actually present in the spectrum.

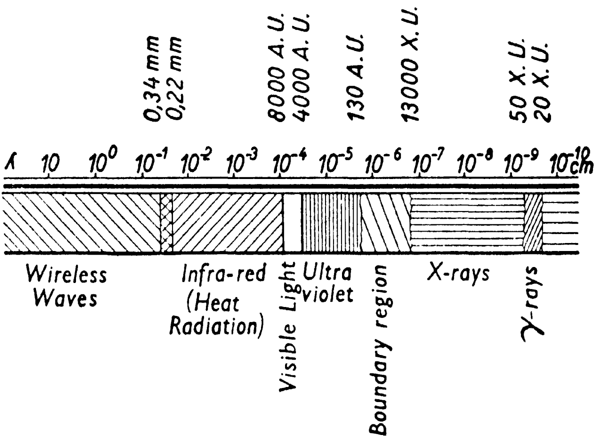

Fig. 67. Spectrum of electromagnetic vibrations.

Only by this assumption can we attain the complete unity of all electro-magnetic radiation. It has its common source in white light and therefore possesses the same nature. Light is the unity of all wave radiation which exists. Wavelengths describe the continuity of the spectrum but not the structure of light itself. For light is a unity which can be divided up into different wavelengths without being their sum, just as the crystal is made up of atoms. Light is a kind of perfect crystal. The rays of different wavelengths which can emerge from it can not be recognized in isolation but must fall perfectly into the unity of white light. Shortly expressed, in white light every wavelength appears superseded, as the atom in the perfect crystal, and the whole spectrum lies in the unity of light in no other way than does the lattice in the unity of the crystal, not as reality but as possibility. In the same way as the lattice or any of its planes can be isolated from the unity of the shape by means of X-rays, cleavage, or percussion figures, and just as they can in that way be regarded separately, the sun's light can be divided into the spectrum which was superseded in it. Just as crystal shape and crystal lattice, although joined to a perfect unity, could still be clearly differentiated, white light can also be distinguished from the spectrum or its single rays. Light as unity is a crystal, the single rays, however, taken out of that unity, can not be regarded as crystal any more than the physical atoms of a mineral. The fact that the spectrum is partly invisible and partly visible is an interruption of its continuity which has nothing corresponding to it in the crystal. The visible part is manifested by colours, the invisible part by energy. But energy and colour are not identical any more than the two are identical with light as a whole. The important point of energy is that it is capable of imparting motion to bodies whilst that of colour is that they can be appreciated. Light passes indifferently, in fact passively through the world of bodies and does not in any way take part in that world, but colour destroys spatial structure and allows the inorganic to flow into time in the way of the organic, whilst energy leaves bodies as such but gives them the impulse causing motion.

Light, as we have realized, is the mode of the organic in the world of the inorganic. When divided it appears in two types of rays with which it forms a trinity as a unity. White light compared to colour does not appear organic, but inorganic, as the crystal. Colourless light remains closed to the world of bodies. The colour amongst the three represents the mode of the organic and finds its purest expression in the significance of the soul of life, as colour of the blossoming plant. Energy radiation, however, has the mode of the spiritual which does not dissolve but allows individuals to exist although it causes them to move and determines their fate.

In that way the three modes of being appear in light in the degree of the inorganic as a unity in the white light of the sun, or that of any other glowing body, as a trinity of light, colour and radiation energy. Light is the perfect crystal, which in perfection exceeds the diamond because it has in its shape directly grasped infinity itself.

Light is the crystallized flow of time.

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